ELECTRIC
POWER PLANT ENGINEERING.

ELECTRIC POWER PLANT ENGINEERING

BY

J. WEINGREEN

NEW YORK
McGRAW-HILL BOOK COMPANY
239 WEST 39TH STREET
1910

PREFACE

In the last decade the electrical industry has developed to such an exceptional extent that it has become desirable to formulate some sort of rules and regulations which may be used as guides in the various problems of construction arising in every-day practice. Up to the present there has been published but little suitable literature dealing with the control of the generation and the distribution of electrical energy. The author therefore feels justified in offering this treatise to the technical public, with the hope that it may at least partially fill the void. Its object is to offer to the contractor and engineer, as well as to the student, material which will help them to understand the methods of handling electrical energy. It is assumed that the reader is familiar with the basic principles of electrical engineering, as well as with electrical machinery and the ordinary instruments. The aim has been throughout to restrict theoretical discussions as much as possible and to eliminate higher mathematics. The book is intended as a useful handbook for those concerned with practical problems.

I have limited the work to American power station engineering. The material represents exclusively present-day practice and the lines which future development may be expected to follow are pointed out.

All conclusions set forth herein are based on personal experience and a careful study of recognized standard constructions and the opinions of such authorities as Professor Charles P. Steinmetz, Dr. Louis Bell, Frank J. Sprague, W. C. Gotshall, Paul M. Lincoln, Professor Dr. F. Niethammer, Stephen G. Hayes, and others.

I am particularly indebted, for assistance and information, to the following organizations: American Institute of Electrical Engineers; Electric Storage Battery Company; Ford, Bacon and Davis; General Electric Company; Gould Storage Battery Company; Hartman Circuit Breaker Company; Indianapolis and Louisville Traction Company; Interborough

Rapid Transit Company; Locke Insulator Manufacturing Company; New York Edison Company; Westinghouse, Church, Kerr and Company; and Westinghouse Electric and Manufacturing Company.

I desire also to recognize the assistance rendered by the publishers of the *Electric Railway Journal*, the *Electrical World*, the *Electric Journal*, the *Electric Review and the Western Electrician* and the *Elektrotechnische Zeitschrift*.

The author further desires to express special gratitude to Mr. Trifon von Schrank, C.E., for assistance in editing and proof-reading.

J. WEINGREEN.

NEW YORK, *July*, 1909.

CONTENTS

ELECTRIC POWER PLANT ENGINEERING

CHAPTER I

INTRODUCTION

WITH the development of modern systems of electric traction, power and light distribution, and with the increase in size of the electrical machines, it has become necessary to introduce a prompt and reliable means of control, which will serve at any time as an indicator of the quantity and efficiency of the power generation and distribution. The sub-division of systems into central and sub-stations, often far apart, has further made it imperative to protect expensive apparatus and machinery inside and outside the stations, against any harmful effects of disturbances in the system. These functions are performed by the "switchgear." Under this collective term we include all apparatus, instruments, cells, and compartments with their connections, as well as accessories and place of installation, as distinguished from the term "switchboard." Although this formerly referred to the then simple switching system in the station, it has come to apply to that part of the "switchgear" which is assembled on a row of slate or marble panels. The functions of the "switchgear" may be summed up as follows:

1. To start the machines, to maintain them in service, or to cut them out of the system.

2. To gather and distribute the electrical energy, to control its consumption and output, and to record its characteristic fluctuations.

3. To afford protection against disturbances due to short-circuits, lightning, overload, or other causes, either in the entire system, or in any individual portion of it.

4. To afford protection for operators. The switchgear in general is the flexible link between the source of supply and the consumer. In designing such a linkage, one must take into consideration the best economy, reliability, adaptability, and efficiency of the service in the near future, as well as the unknown conditions of the more remote future.

The main part of the switchgear is the switchboard. It constitutes the nerve center of the entire system, whence the four above-mentioned functions are performed. We distinguish between two kinds of switchboards.

A. Direct-control switchboards, which have all instruments and apparatus fastened on them (direct-current and low-tension alternating-current switchboards).

B. Distant-controlled switchboards, which have the busbars, oil switches, circuit breakers, etc., located away from the panel, and hence operated by means of cranks, levers, toggles, chains or gears, or by means of motors or solenoids (high-tension and extra high-tension switchboards).

In order to be able to perform its functions it must respond to the following conditions:*

1. The apparatus and their manner of installation must be fireproof (installed on slate or marble).

2. The conduits and connections which carry current must be so chosen as not to become overheated.

3. All parts must be easily accessible.

4. All live parts with the exception of those of low tension must be kept away from the front of the board. In general, high tension should not be carried to the board.

5. The arrangement of the wires should be symmetrical and as simple as possible.

6. As far as practicable and without unnecessary complication of the arrangement of the apparatus, it should be rendered impossible to make a wrong connection which would result in serious consequences.

7. The possible enlargement of the switchboard should be taken into consideration.

8. A disturbance in one part of the board should not affect the entire system.

* "The Standard Handbook for Electrical Engineers." McGraw Publishing Company.

9. A sufficient number of safety devices should be provided.

10. All necessary instruments and apparatus for the operation and control of the output of the generators and feeders should be installed.

The apparatus and instruments used must naturally be suited to special cases, low-tension d.c. requires different apparatus from a high-tension a.c. The apparatus must be adapted to the kind of current, d.c. or a.c., to the voltage, to the kw. rating of the units and to the local conditions of the plant. We accordingly divide switchgears into two main groups, i.e.:

d.c. switchgear.

a.c. switchgear.

The first group includes mainly direct-controlled, and the second, both direct and distant-controlled switchboards.

It is characteristic of American practice that products manufactured on a large scale are standardized, a method which allows of better, quicker, and cheaper construction of products, together with more accurate and economical design This also has reference to the production of switchboard panels. The installation of such standard panels in a station requires a minimum amount of time, money, and intelligence, which is of especial advantage in the delivery of such material to foreign lands. The panels are carefully tested before shipment. (The General Electric Company's test voltage for instruments rated up to 1000 volts is 2500 volts, and double the service voltage for instruments of higher rating.) The panels most often standardized are those used in railway service and, to a certain extent, those for lighting purposes. Low and medium-voltage boards are distinguished by the fact that a separate panel is supplied for each generating or feeding unit. The entire board consists of a number of unit panels or groups. Separate panels are required for each generator; d.c., synchronous, or induction motor, for the d.c. and a.c. sides of synchronous converters, for transformer sets, storage batteries, groups of arc or incandescent lamps, for every feeder or group of feeders, and in large stations for the power-house instruments.

Another division is sometimes made according to kind of current and system, as, for example, single, double, three, four,

and six-phase a.c. system, or two, three, or five-wire d.c. system. A large number of combinations is therefore possible, covering all cases arising in practice.

Although American switchboard arrangements are less decorative and simpler than those in European use, they nevertheless afford easier orientation and safer operation. A single glance at the board will at once reveal the number of the different units in the plant and the ways and means for their control. The symmetrical arrangement of connections on the back of the board makes possible an easy and safe access, and facilitates tracing of connections.

PART I

DIRECT CURRENT

CHAPTER II

DIRECT-CURRENT GENERATORS

In the last decade electrical energy in the form of direct current has predominated for traction, as well as for light and power distribution. Due to the increase in variety and size of the applications of electrical energy and the advance in inventions and improvements in the field of a.c. apparatus, especially motors, the d.c. is being steadily replaced by the a.c. This does not mean that the a.c. is in all cases a substitute for the d.c., for, on account of its characteristics, the d.c. is in some instances indispensable, while under other special conditions it may be more advantageous.

We will classify the d.c. sources as follows:

1. Generators.
2. Converters (synchronous converter, mercury rectifier).
3. Storage batteries.

Fig. 1 shows a wiring diagram of a generator equalized on the negative. The generator has a compound field-winding consisting of a shunt and series coils. The shunt field-winding has great inductance on account of a large number of turns. It is connected on one side to the negative and on the other side through a field-discharge resistance switch and a variable resistance to the positive. When the generator is started the residual field is sufficient to generate a low voltage which then builds up rapidly, the field current and machine voltage mutually reacting to increase each other. The machine voltage does not increase in proportion to the field current. After a short time it reaches a certain value which is approximately the normal voltage of the machine. The coils of the series-winding contain few turns of low resistance and are wound on the same pole as the shunt coil. The shunt-winding is predominant in its effect, and the series-winding may either intensify or oppose the magnetism produced by the shunt-winding. To run compound machines successfully in parallel

it is necessary to connect their series field-windings in parallel through a low-resistance connection, so that if the load on one machine increases, the additional current will divide through the series coils of the other machines and raise their voltage correspondingly. This connection between the machine sides of the series coils is called the equalizer. We therefore have

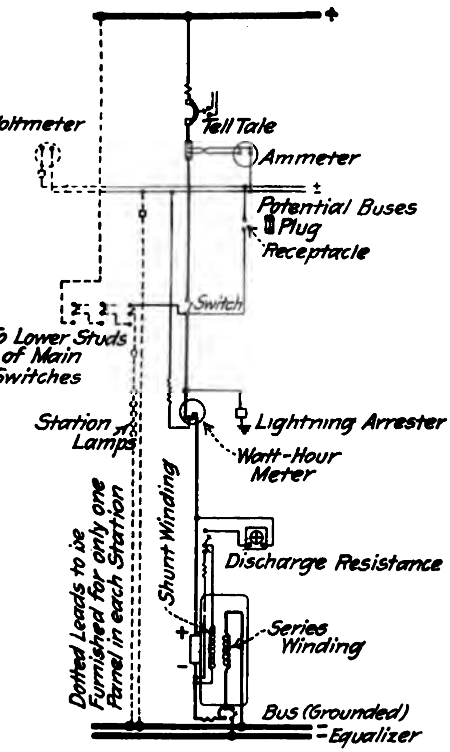


Fig. 1.—Wiring Diagram of a Single-Pole Direct-Current Generator Panel, Generator Equalized on the Negative Side.

in the case of several generators, one positive, one negative, and one equalizing bus, each of which connects the respective poles of the machine in parallel. The method of connection shown is used in the case of large central stations with several generators, and affords a considerable saving of copper in cables. The positive bus is mounted on the back of the switchboard, while the negative and equalizing buses are installed in the

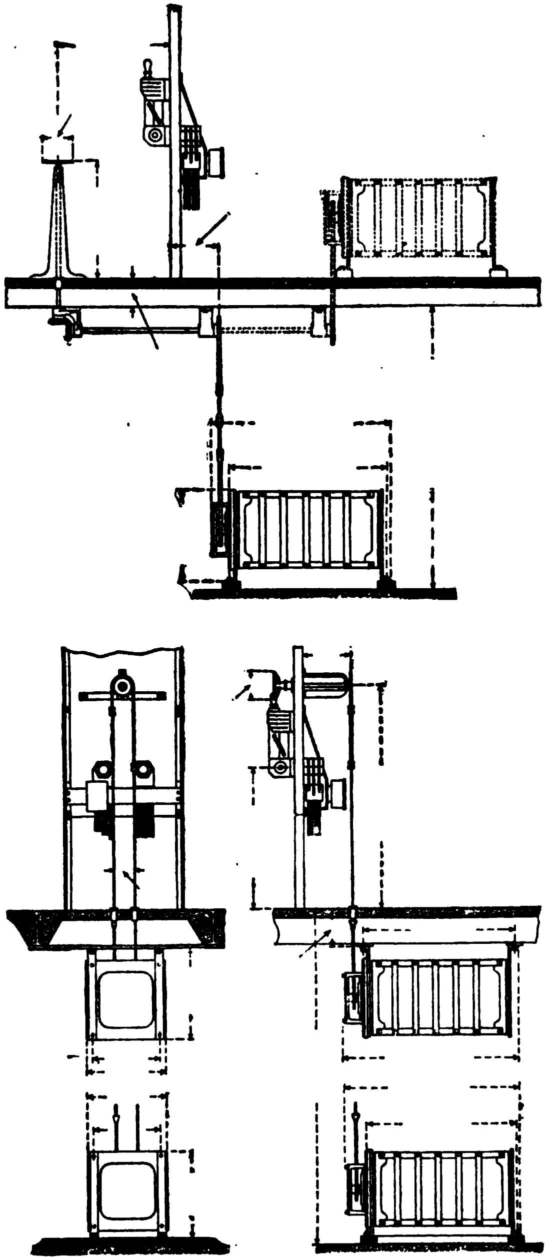


Fig. 2.—Methods of Mounting Field Rheostats.

foundations of the machine. The apparatus for putting the machine in and out of service and for regulating and recording the current and e.m.f. are as follows: A quick-break lever switch, which is one of the main connections between the positive brush of the generator and the positive busbar. In case it is necessary to repair one of the machines it must be disconnected from the live bus, for although the machine is not supplying energy, there is, nevertheless, a current from the bus to

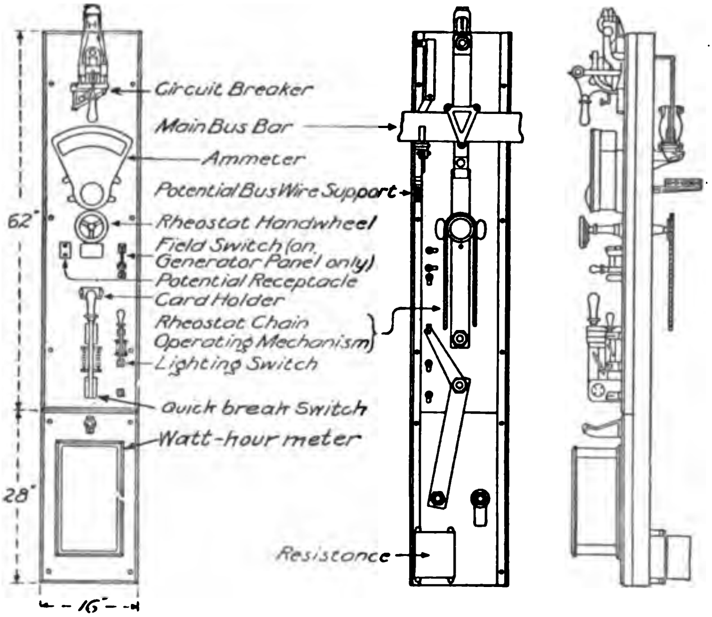
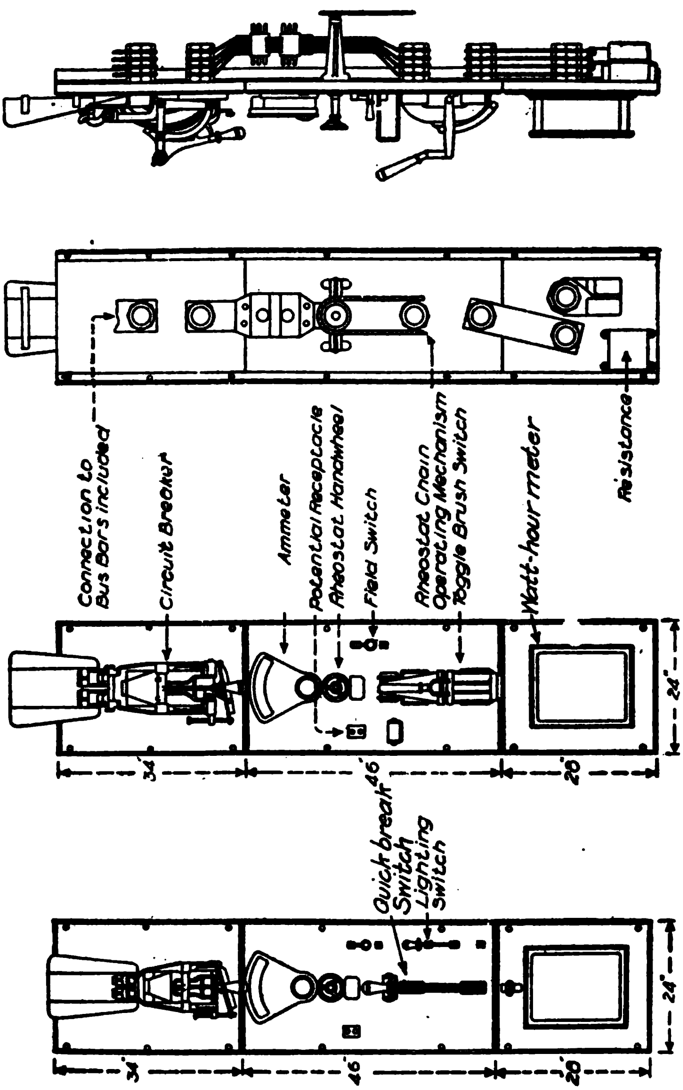


Fig. 3.—Generator or Synchronous Converter Panel for Ratings Not Exceeding 800 kw.

the machine if the connections are not open, a condition which would render handling of the machine parts unsafe. The lever switch in the connection to the equalizer bus and the automatic circuit breaker in the series-winding circuit serve the same purpose. In addition to the above, a further means of disconnecting the machine is provided in the form of an automatic circuit-breaker which is connected to the bus on the positive side of the machine. This apparatus operates in case the positive side of the machine is accidentally grounded. Since the negative is previously grounded (in case of railways, being connected with



1000 and 1200 Kw.

1500 Kw. and Over

FIG. 4.—Generator or Synchronous Converter Panel for Ratings Exceeding 800 kw.

the rail), an excessive flow of energy through the earth would take place, which could seriously damage the machine. The rheostat for adjusting the field current of the machine is generally operated directly from the switchboard by means of handwheels, chains, and sprockets. In case it becomes impossible to operate from the switchboard, on account of the large

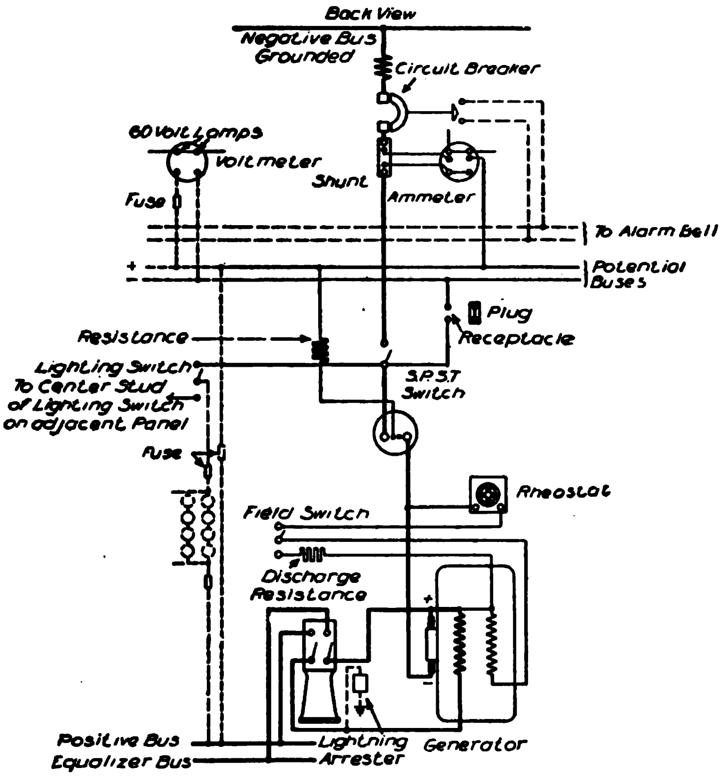


FIG. 5.—Wiring Diagram of a Single-Pole Direct-Current Generator Panel, Generator Equalized on the Positive Side.

size of the rheostat or lack of space for setting it up near the switchboard, it is operated by means of a pilot wheel mounted on a tripod in front of the panel corresponding to the respective generator. (See Fig. 2.) This facilitates reading the instruments which indicate the necessary adjustment.

For generators, ammeters are always necessary. They indicate whether or not the load is properly divided between them.

The connection is made by means of a shunt. It is desirable to locate the shunts as near the instruments as possible, thus avoiding the use of long leads. One voltmeter is sufficient to indicate the voltage of all the machines or busbars, the connection being made through plug switches. The voltmeter is protected against abnormal voltage by a renewable fuse. For

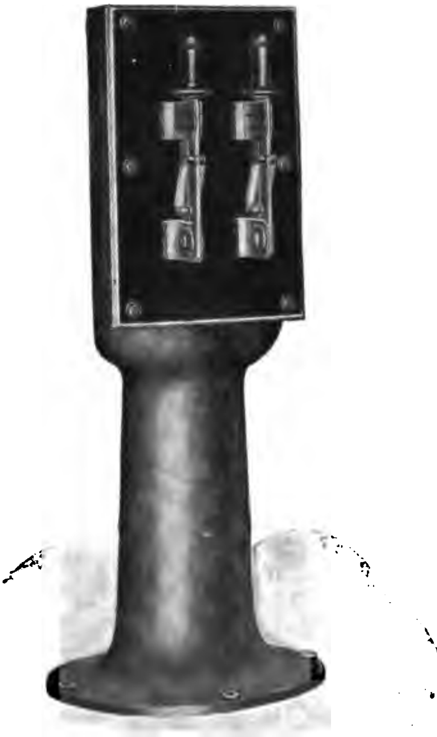


Fig. 6.—Pedestal for Main and Equalizer Switches.

large boards the voltmeter is placed on a swinging bracket on the side of the generator panel. Watt-hour meters are desirable in so far as they indicate the energy output of the individual generators. Potential wires across the backs of all the panels serve to ease the connections for the respective instruments. They are connected to the positive and negative sides of the machine at any convenient points. A lightning-ar-

rester is inserted between the quick-break switch and the watt-hour meter in order to protect the machine and instruments against lightning. A number of incandescent lamps may be inserted across the main voltage as shown by the dotted line on the diagram. In order to call attention of the operator to the

FIG. 7a.—Panel for Main and Equalizer Switches (Front View).

fact that one of the circuit breakers on the positive side has opened, an electric tell-tale is connected with it, which rings when the circuit breaker opens. Instead of tell-tales, signal lamps are sometimes employed. Figs. 3 and 4 show the arrangement and dimensions of generator panels for various kw. ratings as manufactured by the General Electric Company. Such panels can be used when either the positive or negative

bus is mounted on the board. In the latter case a change in the connections between the ammeter and the shunt and a dif-

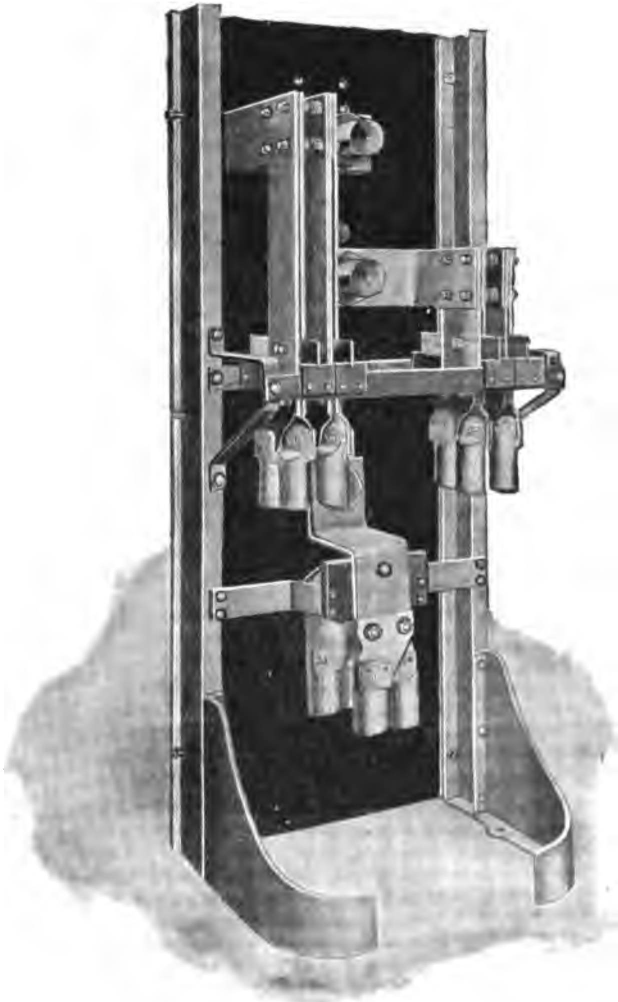


FIG. 7b.—Panel for Main and Equalizer Switches (Back View).

ferent location of the lightning-arrester is necessitated. (See Fig. 5.) This condition often obtains in practice in small central stations. The negative bus on the board is grounded, while the generator is equalized on the positive side.

The panels are made of slate or of white Italian or blue Vermont marble, 2 inches thick and from 16 to 24 inches in width, and are built in two or three sections, giving a total height of from 90 to 108 inches (G. E. make). The supporting framework is composed of angles and tees. Gas pipes connected to the panels with movable cast-iron clamps have recently come into use. For connections between different instruments, apparatus, and busbars for higher current values,

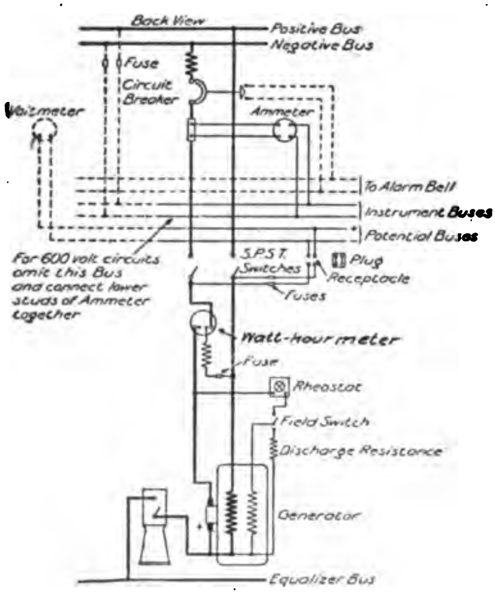


FIG. 8.—Wiring Diagram of a Double-Pole Direct-Current Generator Panel, Generator Equalized on the Positive Side.

copper strips are employed, allowing one square inch per 1000 amperes. Standard thicknesses and widths are used, sometimes combining several strips for one connection, with a ventilating space between them. Aluminum may be used in place of copper, in which case the current density may be taken as 750 amp. per sq. in. These strips must be carefully bent in order to bridge other strips, or contact studs of equal or different polarity. For voltages up to 600 it is customary to allow a minimum space of one inch between connections or between live parts and ground. The Westinghouse Company

employs elongated contact bolts in place of bent copper strips. These bolts are copper rods of convenient lengths with brass castings similar to a union and with both right and left-hand threads. A straight connection between one set of bolts bridges a similar connection between another set. The standard sizes of busbars are 2 in. by 0.25 in., 3 in. by 0.25 in., 5 in. by 0.25 in., and 10 in. by 0.25 in. These and other sizes

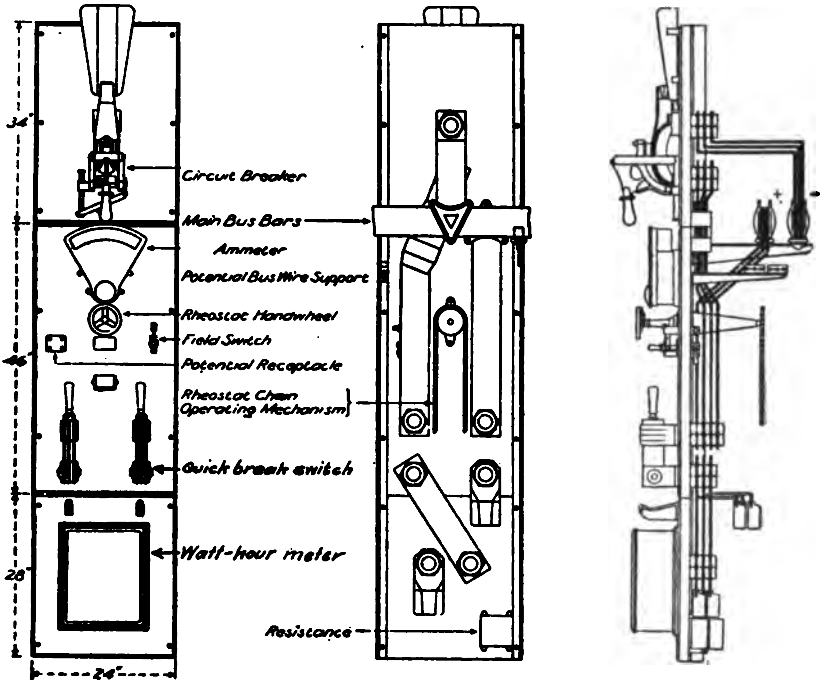


FIG. 9.—Double-Pole Generator Panel for 550 kw. 250 Volts.

are used for connections. All live parts are designed for a rise in temperature not exceeding 20° C. at normal load. The apparatus should be designed to perform its rated functions accurately and safely to meet successfully the most severe conditions that may be imposed upon it, and to present a handsome appearance.

The circuit breaker for the negative side and the equalizer switch in Fig. 1, and the equalizer switch and positive switch

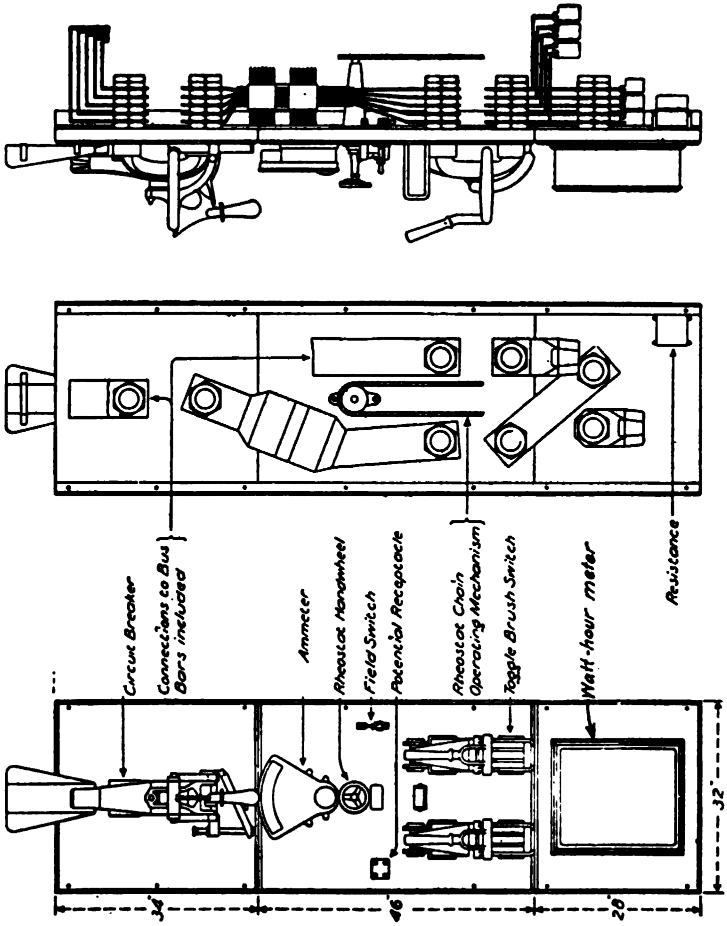


FIG. 10.—Double-Pole Generator Panel for Ratings Exceeding 550 kw.

in Fig. 5, are mounted on separate pedestals or panels near the machine so as to facilitate handling. (Figs. 6 and 7.)

Up to this point we have treated switchboards having one of the buses either positive or negative mounted on the back of the board. This construction has the advantage of greater insurance against short-circuiting, since with the uninsulated live parts only one polarity prevails. These switchboards are mainly employed for railway service up to 600 volts. For 125, 250, and 600 volts, and from 25 to 1000 kw., double-pole switchboards are often used, having both buses mounted on the back of the board. They must, therefore, have two lever switches on the board for both current directions. Hence, the pedestal near the machine holds only the equalizer switch. In all other respects connections, instruments, etc., are identical with those of the first-mentioned case. Fig. 8 shows a wiring diagram, and Figs. 9 and 10 show a switchboard for this class of machine. The mounting of the positive and negative buses should be noted. They are of the same standard width and thickness as noted above. The buses are designed to carry 1000 amp. per sq. in. for the normal load, plus a certain guaranteed percentage for overload. They are mounted on insulators attached to brackets, giving for the positive bus a distance of 5 in. from the board for normal sizes of apparatus and 11 in. for larger sizes. The negative bus is 6 in. from the positive one. (Fig. 11.) Since we have a fixed distance between the busbars and the upper edge of the panel and assumed distances between instruments, we can easily lay out with great accuracy the bending and drilling of copper connections. When strips of over 2 inches in width are to be connected with busbars of 3 in., 5 in., or 10 in., we may use special cast-iron clamps instead of resorting to drilling, riveting, and soldering. (Fig. 9.)

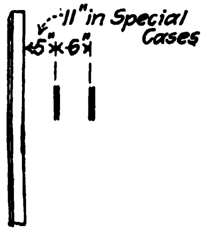


FIG. 11 —Method of Mounting of Direct-Current Busbars.

For generators of smaller rating and voltage, as for instance 25 to 100 kw., and 125 to 250 volts, the equalizer bus is also mounted on the board. This eliminates the pedestal in front of the machine, and in place of it a three-pole lever switch on

the board is used, which takes care of the positive, negative, and equalizer sides of the machine. (Fig. 12.) The rheostat is much smaller and is mounted on a tripod or on pipe supports on the back of the board.

In order to throw one generator into parallel with others in service, proceed as follows:

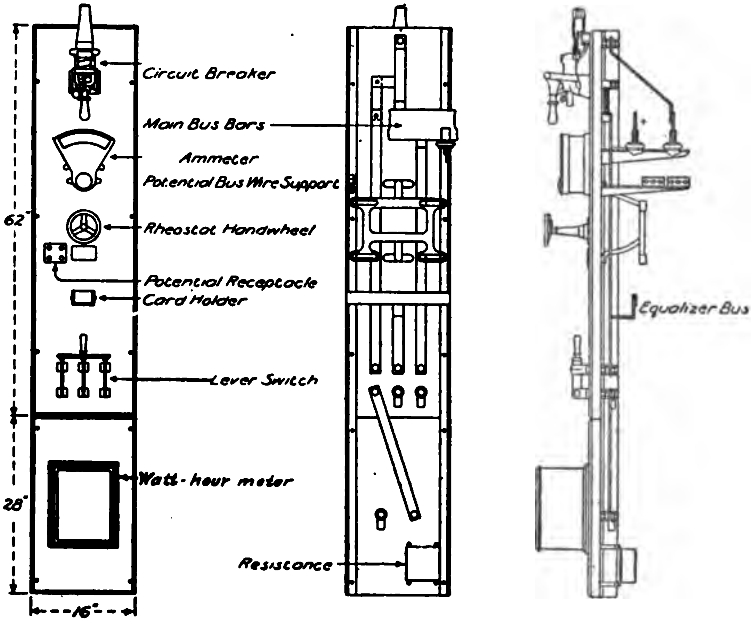


FIG. 12.—Generator Panel for 125 and 250 Volts, Ratings from 25 to 100 kw.

1. Close main and equalizer switches (on pedestal or panel near machine).*

2. Close field switch (on panel).

3. Close circuit breaker.

4. Insert potential plug in receptacle and adjust voltage by means of rheostat.

5. When the proper voltage is obtained, close the other main switch.

* If one or both lever switches are on the board, it is obvious that they perform the same functions as stated above. Hence the same procedure should be followed, as here indicated.

CHAPTER III

SYNCHRONOUS CONVERTERS

A SYNCHRONOUS converter is essentially a d.c. generator, possessing, besides the ordinary commutator, several collector rings which are connected with the armature winding at corresponding points. When this machine is driven through the application of mechanical power it delivers either direct or alternating current. If on the other hand electrical energy is employed to drive the machine, available mechanical energy will be the result. It is thus evident that the machine can be run either as a synchronous or d.c. motor or as a converter of a. currents into d. currents or vice versa. In this chapter we will treat only the d.c. side of the converter.

In the first case, when the converter acts as a d.c. generator, the switching arrangements are almost identical with those of the ordinary d.c. machine. Fig 13 differs from Fig. 1 only in that the negative side of the machine is grounded directly or is directly connected with a grounded negative busbar, so that we have only one lever switch for the equalizing bus. This switch is located near the machine or on the frame of the converter itself. The automatic safety device which guards against grounding is found on the a.c. side of the generator. The automatic circuit breaker on the positive side is supplied with a special coil which opens the circuit breaker at a given low voltage. This winding is connected with a speed-limit device mounted on the shaft of the converter, which closes the circuit of the winding at a given speed limit and operates the circuit breaker. Figs. 3 and 4 may also represent converters for which the positive bus is mounted on the board. The series field-winding of the converter is connected to the negative side. The above considerations apply to a converter started from the a.c. side, which is the most frequent case in service, because the converter does not require to be synchronized. (See Chapter XXI.) After the converter has been started on the a.c.

side, and it is desired to throw it in parallel with other machines on the d.c. side, proceed as follows:

1. Close the equalizing lever switch on the machine.
2. Close the automatic circuit breaker on the board.
3. Ascertain the voltage, using plug switch and voltmeter on movable arm.

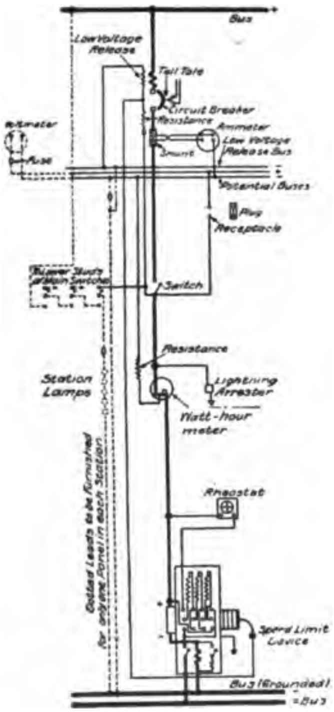


FIG. 13.—Wiring Diagram of a Continuous-Current Synchronous Converter Panel.

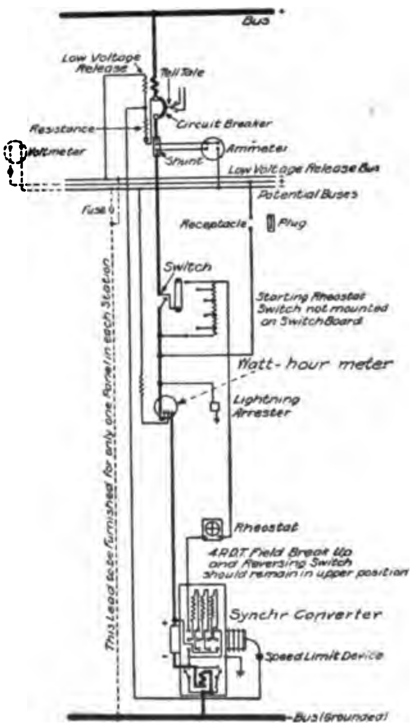


FIG. 14.—Wiring Diagram of a Single-Pole Direct Current Inverted Converter Panel.

4. When the desired voltage is reached close the positive lever switch on the board.

If the converter is to be started on the d.c. side, the switchboard must be provided with a starting rheostat switch. The converter must be synchronized with the line. This must also be done when the machine is started by a separate induction motor. (See Chapter XXI.) To start, proceed as follows:

1. Close the field switch.

2. Close the main switch, allowing the starting rheostat to remain in circuit.

3. When normal speed is reached gradually throw out the starting rheostat.

4. Change the field strength by means of the rheostat until the synchronism indicator shows equal synchronism with the a.c. generator.

5. Close the a.c. oil switch.

Fig. 13 shows a compound field converter—hence the equalizer buses. Such machines are used for variable load in traction systems. In case converters with only shunt field-windings to be run in parallel, the equalizer bus is omitted. This type of machine is especially adapted to electric lighting or electrochemical purposes where the d.c. voltage requires special control. This control is taken care of on the a.c. side by a potential regulator (see potential regulator), inserted between the low-tension side of the power transformer and the converter.

Fig. 14 shows a wiring diagram for a d.c. inverted converter. The speed of this machine, like that of a d.c. motor, depends essentially on the field strength. The speed increases with a decrease in field strength, and vice versa. It follows that the series field should be weak, for otherwise we should have a constant change in speed, giving rise to variable frequency in the delivered current. A lagging current weakens the field, thus increasing speed and frequency, and making it possible under certain conditions with inductive load for the machine to run away. Particular attention should therefore be directed towards maintaining sufficient field strength, in order to avoid excessive speed, particularly when the given converter drives a second machine which reconverts the a.c. into a d.c. Speed-limit devices, capable of operating an automatic circuit breaker are mounted on the shafts. The starting rheostat is usually mounted separately, or in case the watt-hour meter is located off the board, the starting rheostat is put in its place on the base of the panel.

CHAPTER IV

MERCURY RECTIFIERS

Of late a new system for converting alternating into direct current has been developed. Up to the present this system has been most widely used in electric automobile service, or wherever batteries are charged. Formerly in cases where small batteries were to be charged, and where no low-voltage direct current was available, it was necessary to provide very costly and cumbersome apparatus. The best known devices for this purpose were:

1. A motor-generator set whose disadvantages are high cost, large consumption of floor space, and requirement of higher intelligence for operating. The efficiency at full load for charging batteries is comparatively low, and at light load, very low.

2. Single-phase synchronous converter. This is not as flexible as the motor-generator, particularly as regards voltage, and the higher intelligence requisite for starting and operating adds another disadvantage.

3. Synchronous or mechanically driven rectifier, which though small requires considerable attention, as the d.c. brushes are apt to spark badly and require constant renewals.

4. Chemical rectifier. This machine has not justified itself in practice on account of the variability and uncertainty of the charge. Its efficiency is low under all conditions.

The mercury rectifier has none of these disadvantages. Its cost is low, it requires little space, and its efficiency of conversion at low or full load is high. It is flexible, safe in operation in that it is impossible to discharge the batteries by a reversal of current, and it has no moving parts. It is on the whole a very simple machine. The only disadvantage lies in the fragility of the glass bulb, but this is compensated for by its low cost. The process of rectifying is based on the fact that it is difficult to excite a cathode in mercury vapor. Since an electrode cannot become a cathode by itself, the current must

always have one direction, from the electrode to the vapor. The theory of this phenomenon is treated in different ways by Dr. C. P. Steinmetz, and by Peter Cooper-Hewitt. The equipments of the apparatus as manufactured by the two companies (General Electric Company and Westinghouse Company) do not differ essentially from each other. Fig. 15 shows a

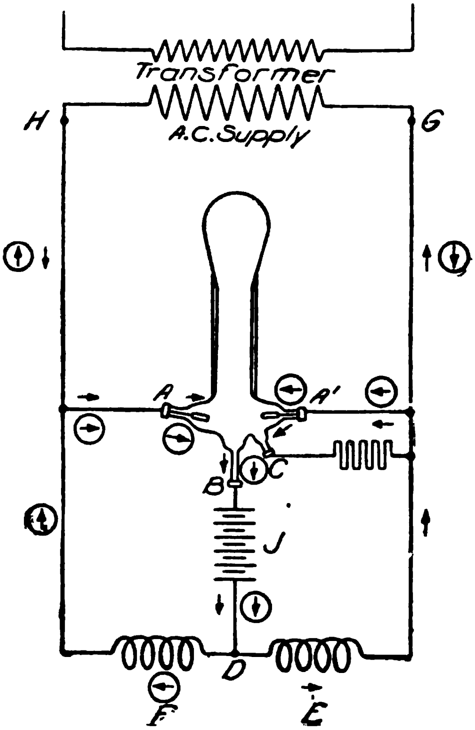


FIG. 15.—Diagram of Connection of a General Electric Co. Mercury Rectifier.

general wiring diagram of the mercury rectifier of the General Electric Company. The secondary winding of a transformer which reduces the available alternating e.m.f. to a given value (usually 110 or 220 volts 60-cycle single-phase), is connected in parallel with the anodes A and A¹ of a glass tube containing mercury vapor in vacuum, and with two reactors, also in parallel. The cathode B is connected through the load with the binding post between the two coils.

According to the theory of Dr. Steinmetz, the mercury vapor offers a very high resistance to the passage of electricity, in fact, it may be considered almost a non-conductor. If the vapor is ionized it becomes a good conductor, but in one direction only. By means of employing a mercury electrode as a cathode, ionized mercury vapor may be liberated. The initial ionization of the mercury vapor is accomplished by a small starting anode, C, which is brought into contact with the cathode by a mercury bridge formed by slightly shaking the tube. The breaking of this mercury bridge starts a small initial arc, and the arc thus obtained excites the cathode, giving the necessary ionized vapor, which enables the working anodes immediately to become active and the tube to start. The two anodes, A and A^1, serve as electrodes for the alternating current. The upper halves of the cycles are sent through the ionized vapor alternately by both anodes. Since the displacement between waves sent through both anodes is 180°, the current at the cathode is a pulsating direct current, varying between the values of zero and the maximum. A current of this nature, identical in its characteristics with the alternating current, which it replaces, is not serviceable. Although the zero value is but momentary, it is nevertheless sufficient to cause the cathode to lose its excitation. This causes the arc which carries the current between cathode and anode to be extinguished. A device designed to keep the current value constantly above zero is therefore necessary. This is accomplished by the reactors. The coil, E, is charged during the rise of the wave from zero to maximum. The coil discharges according to the laws of induction in the same direction as that of the main current. This has the effect of keeping the value of the current above zero until it meets the rising second wave. The overlapping thus caused maintains the excitation of the cathode and the arc. The same action takes place between the wave of the anode, A^1, and the coil, F. The resulting current is a pulsating one, but the pulsations are shallower on account of the action of the coils. Fig. 16 shows the glass tube with the two anodes, starting anode and cathode, and the wiring diagram of commercial switchboards. On the board are mounted an ammeter, a voltmeter, a double-pole a.c. line switch (for example, to connect secondary winding

to transformer), a double-pole d.c. load switch, one double-pole starting switch, one single-pole load switch, necessary fuses and circuit breaker to protect the rectifier from overload. A starting rheostat is mounted on the gas-pipe frame of the panel. The rectifier is started through the rheostat and is then thrown onto the load. A signal lamp connected in parallel with the rheostat is mounted on the board

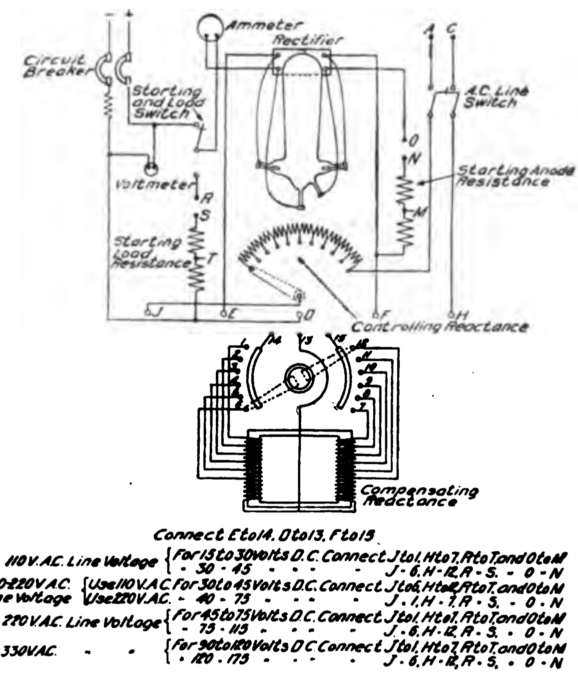


FIG. 16.—Wiring Diagram and Panel of a Mercury Rectifier Outfit (General Electric Co.).

which, when burning, indicates that the load is on the line and that the rheostat should be cut out. The lamp remains dark when only the load is in circuit. The anodes are connected directly with the reactors, and the cathodes with the load. Taps lead from the reactors to a dial switch on the panel, through which the current and e.m.f. can be varied within certain limits. Mercury rectifiers are built for ratings of 10, 20, and 30 amp., for single tubes. They may be operated in multiple by addition of certain auxiliary apparatus and can

thus be made to deliver a greater current. They are mostly used with 60-cycle 110 or 220 volt single-phase alternating current, and deliver from 16 to 115 volts direct current. At the present time they are coming into use more and more in larger installations for arc lamps, mercury lamps, and magnetite lamps connected in series.

Fig. 17 is a general wiring diagram of the Cooper-Hewitt mercury rectifier as put forth by the Westinghouse Company. Its action is the same as that discussed above, but the theory of the phenomena is differently explained by Cooper-Hewitt. The

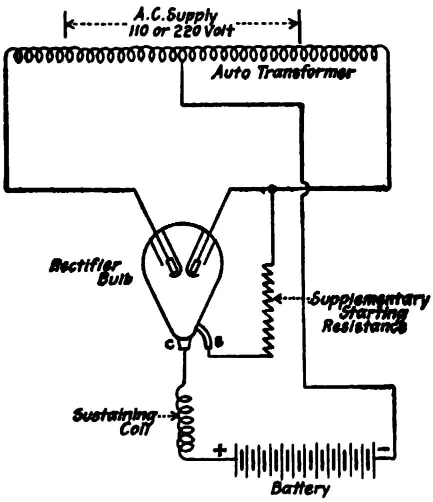


FIG. 17.—Connection Diagram for Battery Charging with a Cooper-Hewitt Rectifier.

electricity can easily flow into the mercury vapor from a metal or graphite contact connected to a source of power. As soon as the current direction is reversed the solid contact offers a very high resistance to the passage of electricity from the mercury vapor to the contact. This resistance can be overcome by a very high e.m.f., and as soon as this condition obtains, the normal current can be established from vapor to contact with a low e.m.f., the resistance having practically disappeared. According to Cooper-Hewitt's theory, the difficulty encountered in establishing a cathode is due to the great resistance which the latter offers to the passage of electricity at

the first instant. As soon as the cathode is established, however, this resistance is minimized. If a single-phase alternating e.m.f. is supplied to the anodes the action is the same as that described under Fig. 15, where we saw that only one-half

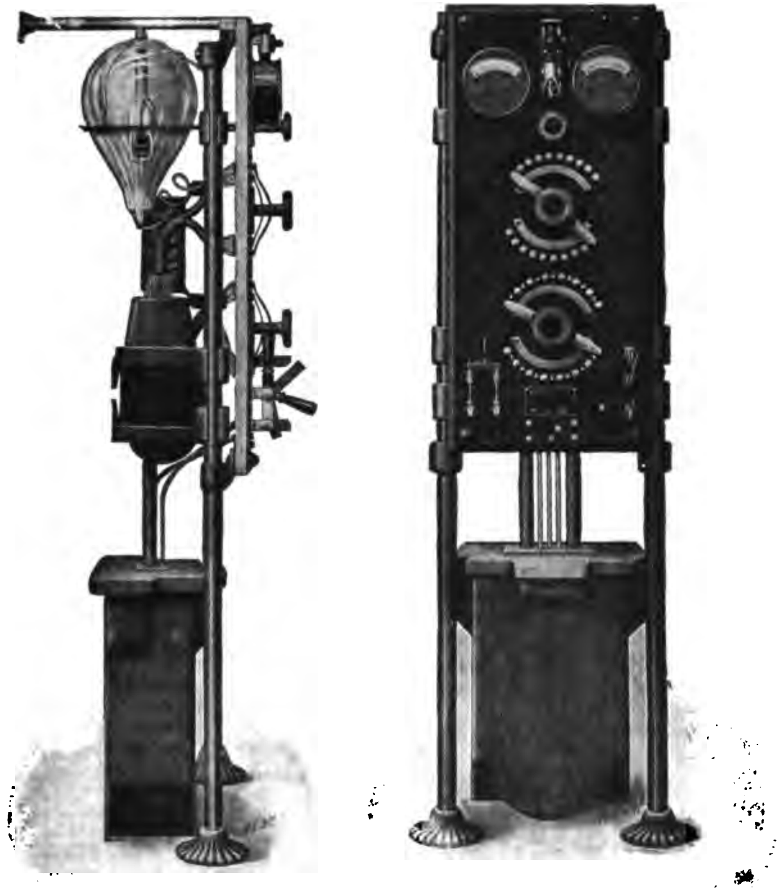


FIG 18.—Panel Outfit of a Cooper-Hewitt Mercury Rectifier.

of the waves pass through each anode. Since the wave halves are displaced 180° from each other, the resulting current reaches zero value at the end of each wave, which again causes a great resistance at the cathode. The zero value must there-

fore be bridged over, and this is accomplished by means of the reactors in the connection to the cathode. The applied e.m.f charges the coil during the rise of the wave and discharges it during the fall of the wave. This causes an elongation of the current waves so that they overlap before reaching the zero value. This overlapping of the rectified current waves reduces the amplitude of the pulsations and produces a comparatively smooth direct current. A momentary metallic contact is brought about between cathode and starting anode by tilting the glass tube. When the metallic circuit is opened by bringing the tube back to its original position the current is not interrupted, as the negative electrode resistance is broken down. The apparatus is in no sense a transformer. It does not convert energy from one form into another. Its action is simply that of valves opening and closing gateways and thus allowing electricity of one direction to flow through a given line. Fig. 18 shows the Cooper-Hewitt mercury rectifier and panel. The autotransformer is placed on the floor back of the panel. It receives the alternating current. A dial switch on the front of the panel regulates the potential. The "sustaining coils" are fixed on the rear of the panel as is also a controlling reactor, by means of which more precise e.m.f. regulation can be accomplished. The tube is mounted in a ring on the back of the panel. A stem on the ring projects through the panel, and by means of a hand wheel attached to the stem a tilting of the bulb can be secured. These rectifiers are used for from 40 to 120-volt direct current, connected to 110 or 220-volt 60-cycle alternating current.

CHAPTER V

STORAGE BATTERIES

The scope of this work does not call for any extended treatment of the construction of storage batteries, as this matter is treated fully by any number of authorities. They will be discussed here only in so far as they constitute an essential part of electric power-station switchgear.

Storage batteries are used as emergency reserves to help out a badly engineered d.c. installation, or for taking up peak loads on a system whose maximum load has outgrown the rating of the generating station. But in designing a new installation they are taken into account to assure efficiency, reliability, and economy of investment and operation.

Storage batteries are used for the following purposes:

1. To regulate the station output.
2. To compensate line losses.
3. To act as reserves in case of shut-downs.
4. To act as equalizers in three-wire systems.

The above functions may be called for singly or together, and may be performed at the central station, sub-station, on the line, or in two or more of these places at the same time. Batteries are employed in railway, light, or motor service.

1. Batteries are used for regulating the station output in two cases.

(a) In the first case the battery is charged by the machines when the outside load is reduced for some length of time, and is discharged on peak loads or at night when the machines are not run. For this reason the generation and transmission of energy up to the point where the battery is installed are made independent of the load variations beyond that point.

(b) In the second case the battery is constantly in service, charging and discharging according to the momentary fluctuations of the load. This is a condition which always occurs in

railway service. Hence we have the terms equalizer, fly-wheel, or buffer batteries.

A battery therefore serves to keep the time and rate of energy generation independent of the time and rate of the load fluctuations. In both these cases the use of batteries has proven highly economical. For maximum efficiency it is essential that all machines should be kept loaded to their full rated power while in service. If storage batteries are not installed, the rating of the machines must be equal to the max-

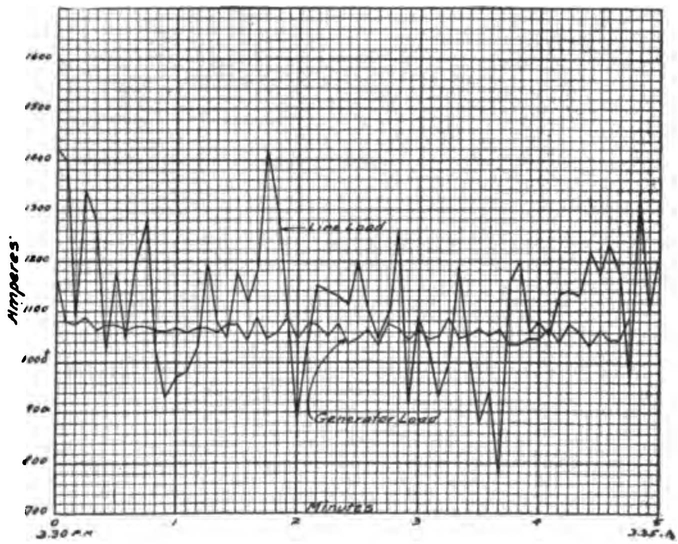


FIG. 19.—Load Curves with Battery in Use.

imum load, even though such load may be of only short duration; hence the station rating is in excess of the average power required. If, on the other hand, batteries are installed, the necessary machine equipment is reduced in size to an amount equal to the average load. At the same time the efficiency is increased by keeping the load factor constant, corresponding to the maximum (efficiency). Since, moreover, the battery is best able to deal with the very kind of loads which are imposed upon it, i.e., small loads of long duration (as night railway service) or sudden fluctuations which most reduce the efficiency of the machines, a proper division of load-

ing will result in maximum fuel economy. By increasing the load factor of the machines and decreasing their service hours, an additional advantage is gained through decreasing the losses incidental to starting and shutting down.

The diagrams in Fig. 19 show the load fluctuations of a system and the influence of batteries on the generator output. The average load on the line is approximately equal to the generator output and fluctuations are taken up by the battery. In this case the generator rating is only 1100 amp., while without batteries it would have to be 1400 amp.

2. If a battery is joined to the line at a distant point, the line carries only the average load instead of the maximum. With a given line drop this affords saving in copper or a higher allowable voltage for a given size of wire. In some cases, where the average load of the line is small, batteries may be used to replace sub-stations. When installed in sub-stations they afford not only a saving in copper and reduction of line loss, but equalize the load on the converter, which therefore draws a constant current from the central station, so that the high-tension line losses are also reduced.

3. The special advantage of storage batteries is their ability to act as reserves. The following cases are the most important arising in practice:

(a) When the central, high-tension transmission line or sub-station is accidentally shut down. In this instance the battery will for a certain length of time maintain the service in the portion of the system affected, allowing the necessary repairs to be made.

(b) At momentary, unforeseen, or excess load, such as traffic congestion or increased demand for illumination on dark days, the batteries will take up such loads before it would be possible to put any additional units into service.

(c) They make it possible to disconnect the transmission line and all machines in the central or sub-stations for a considerable length of time during the night so as to allow of inspection and repairs.

(d) If batteries are used in systems not generating their own power, they make it possible to buy direct or alternating current from other systems when these are not overloaded, and this at a constant rate. Since the price of energy is figured on

the basis of peak load, the gain due to the lower rate of delivery required by batteries frequently offsets the initial cost of the batteries themselves.

If there is any indication of disturbances in the system which might affect the machines, the trouble can be localized by cutting out the machines and throwing in the batteries. The emergency value depends upon the size of the battery relative to the load and the kind and variation of that load.

4. In the three-wire systems, batteries are used as equalizers by connecting the neutral of the system to the middle of the battery, and the other buses to the ends.

When connected to an open circuit, a single element has an

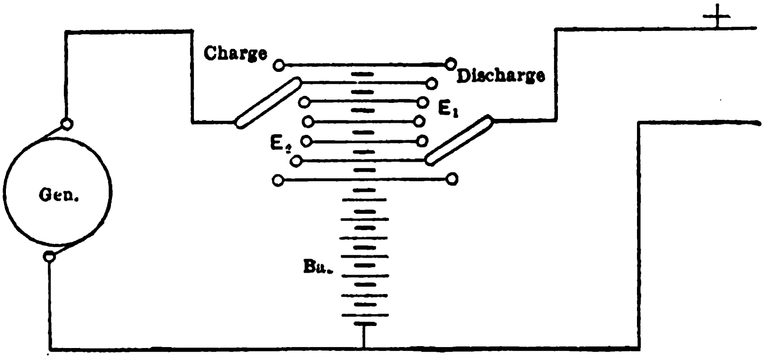


FIG. 20.—Battery Connections with a Double End-Cell Switch.

e.m.f. of 2.08 volts. This tension is called "floating voltage," for if the battery were connected into a circuit of this voltage it would neither be charged nor discharged. When a battery discharges, its voltage drops momentarily, and then remains constant to a point at which it again drops rapidly. In practice it is never discharged beyond a point at which the e.m.f. is 1.8 volts. The initial drop is caused by the internal resistance and partial polarization on the surface of the plates. In charging, the external or impressed voltage must be sufficient to overcome the counter e.m.f. and internal resistance of the cell. The voltage of the battery on charging rises momentarily, and, as before, remains constant until the battery is completely charged, when it again commences to rise. To charge or discharge a battery at a constant rate the e.m.f. must vary

according to the battery's characteristic curve for that particular rate. A battery in circuit will require or produce current only when the outside voltage differs from the floating voltage. When this difference becomes sufficient the battery will operate without further assistance, and so take care of peak loads and large rapid fluctuations (a case which often arises with line batteries).

The operation of the battery is somewhat different when strong fluctuations do not exist or are not admissible, and also when precise equalization and quick response are required. In such cases auxiliary apparatus is used to regulate the charging and discharging. Such apparatus is either hand-operated or automatic. The former is used when the battery is to be put into commission for some length of time. This applies especially to lighting systems. The most usual method of regulation is by "end cells." These consist of a number of cells connected step by step in series with the main battery so as to compensate the voltage drop during discharge. Fig. 20 shows an end-cell arrangement with two switches. The required line voltage is maintained through the regulating switch, E, while charging is regulated by the generator field rheostat and switch, E_2. With this arrangement the generator charges the battery at a higher voltage, and at the same time feeds the line at the normal pressure. The sum of the charging current and line current passes through the end cells, so that these are charged more quickly than the remaining ones; this requires cutting out the cells step by step by means of switch E. The battery should be charged only when the outside load is low. The end switches must be carefully designed so that there shall be no short-circuit between adjacent contacts, or interruption of the circuit while shifting the contact arm. Sometimes they have an additional arm insulated from the main arm and connected with it through a resistance, so that when the two arms are on adjacent contacts, the short-circuiting current is reduced by the resistance. These end switches are usually in the shape of dial switches or straight line glide switches. They are mounted on the switchboard and are operated manually or by motor.

Another method of regulating batteries by hand makes use of a carbon pile, whose resistance depends upon the surface

pressure on the carbon plates of which it is composed. As this pile is connected in series with the battery, any change in the pressure will change the charging voltage.

Automatic regulation of storage batteries depends upon the generation of an additional voltage, which causes charging when added to the bus voltage and discharging when subtracted from it. This extra e.m.f. is used to overcome the counter e.m.f. of the battery. It is produced by a generator called a booster, whose armature is in series with the battery and whose field is automatically regulated through the influence of the load variations.

The simplest case is that of the "shunt booster," whose

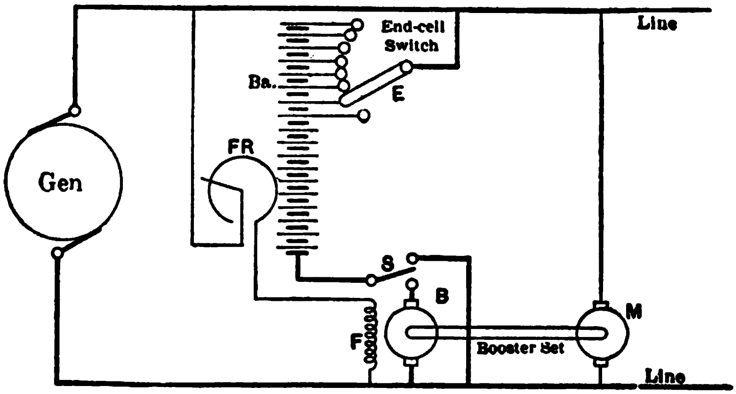


FIG. 21.—Shunt Booster Connection.

field-winding is in parallel with the buses. This machine is used only for regulating the charge, and it accomplishes this through a field rheostat. The connection diagram is given in Fig. 21. The booster is driven by a shunt motor and is disconnected while the battery is discharging. For the discharge regulation end cells are used. Shunt boosters with manual regulation are used in plants where the load variations are gradual and uniform, so that the battery may be charged and discharged for longer periods. This is the case for peak loads of long duration, or when the generators are shut down.

In traction systems where the load fluctuates rapidly within wide ranges a booster must be used whose e.m.f. is made to vary automatically with the load, so that it will add or sub-

tract from the battery voltage as required. These requirements are met by the "differential booster." This machine differs from those previously described in that it has a series field winding in the working circuit in addition to the shunt field winding. In Fig. 22, F_1 is the shunt and F_2 the series-winding. The second winding opposes the first, so that at a certain external load they will balance each other and the resultant e.m.f. will be zero. At this load the generator e.m.f. is equal to that of the battery, so that the latter will neither charge nor discharge. At higher loads the action of F_2 is greater than that of F_1, and the booster e.m.f. is added to that of the battery, causing the battery to be discharged. With

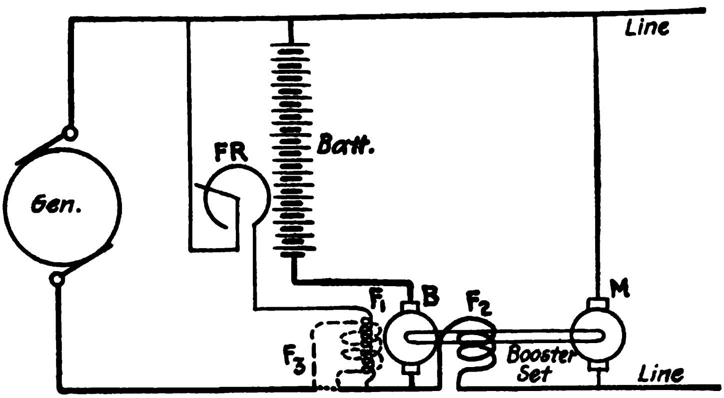


FIG. 22.—Differential Booster Connection.

smaller load, on the other hand, F predominates, and the booster tends to charge the battery. The booster, therefore, tends to maintain a constant load on the generators by enabling the battery to take up the fluctuations. In order to make this combination as stable as possible, a third field winding is put in series with the generator circuit, so that the increased generator current caused by the increased load produces an additional effect which enables the battery to discharge. The object of this third winding is to secure a more perfect and precise regulation than would otherwise be possible, and to keep the division of load between the batteries and machines at the desired ratio.

Instead of exciting the boosters directly from the line, a

separate exciter mounted on the shaft of the motor-booster set, or driven by a separate motor, may be employed. The exciter field consists of two differential windings, one shunt winding supplied at a constant voltage, usually from the station voltage, and one series winding included in the circuit to be regulated. The exciter armature is connected to the booster field through a rheostat. The booster excitation will therefore vary with that of the series field coils of the exciter. This type of booster is called "exciter booster."

When the load fluctuations must be kept within certain small limits an arrangement is used which magnifies the in-

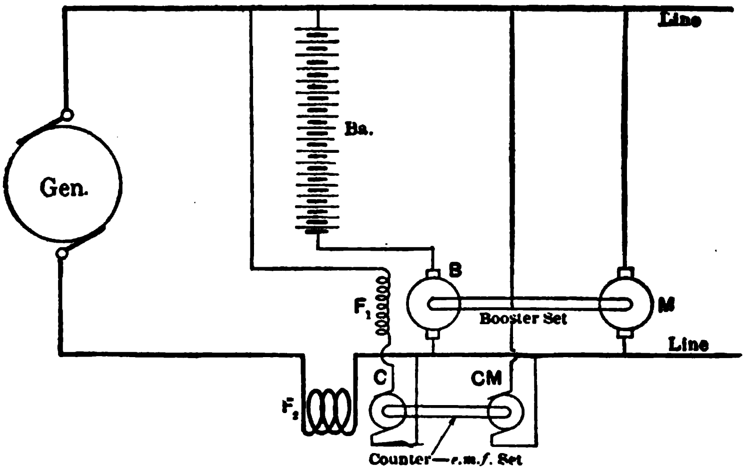


FIG. 23.—Diagram of Connections of a Booster with Counter e.m.f. Generator.

fluence of the variations on the booster. The auxiliary equipment for this purpose consists of what is termed a "counter e.m.f. generator." Fig. 23 shows the connections of this type of machine with the booster and batteries. The operation is based upon the fact that the counter e.m.f. generator is excited by a series winding, F_2, built in the main generator circuit, and that the armature winding of this auxiliary machine is in series with the field winding of the booster and across the busbars, but opposing them in voltage. At a certain external load the e.m.f. of the auxiliary generator exactly balances that of the buses. Since the latter is constant, and since the counter e.m.f. is made to depend on the external load, the

booster voltage is inversely proportional to the output of the station. Adjustable resistances are inserted in the field circuit of the counter e.m.f. generator, which enable precise regulation of the batteries for different numbers and sizes of generators and different average loads. The auxiliary generator is usually mounted together with the booster or is driven by a separate motor.

In still another case the booster is excited by a separate exciter whose field is in series with the counter e.m.f. generator.

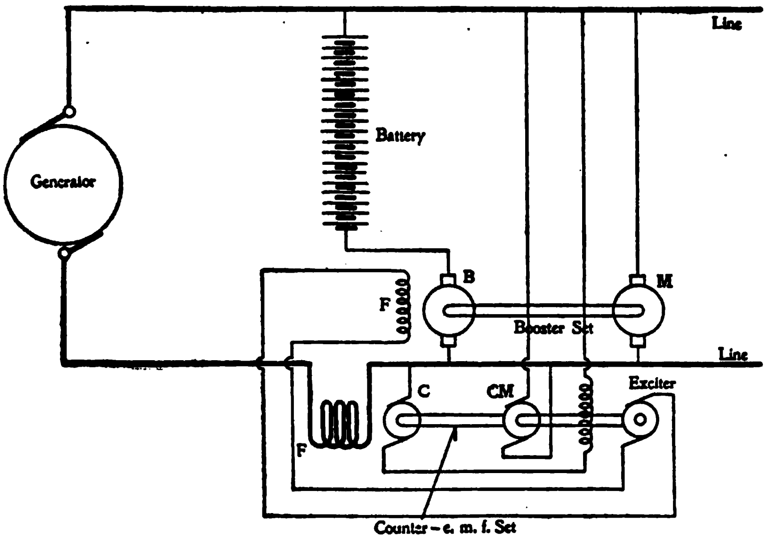


FIG. 24.—Diagram of Connections of a Booster-Exciter with a Counter e.m.f. Generator.

The connections are shown in Fig. 24. This arrangement affords more sensitive regulation, and makes possible the use of a single counter e.m.f. generator for different sizes of boosters and batteries. This is the method used by the Gould Storage Battery Company.

In cases where the load is composed of a constant load from a lighting system, and a variable load from a traction system, a booster called a "constant-current booster" is employed. The field winding of the counter e.m.f. generator under these conditions is in series with the battery feeder, while the armature winding is so connected to the booster field that any tend-

ency to increase or decrease the current in the battery feeder is instantly opposed by a decreased or increased booster voltage. The booster is inserted between the constant and variable loads, so that the latter is supplied either by current through the booster or by this current augmented by the battery current. The current through the booster feeds either the variable load or the battery, according to the requirement of the feeders supplying the variable load.

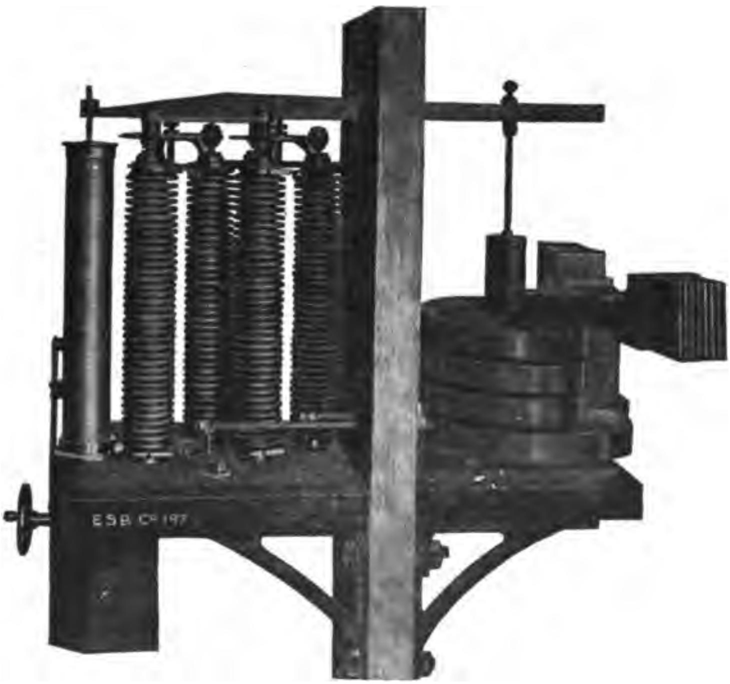


Fig. 25.—Carbon Pile Regulator.

The small and inexpensive shunt booster may be used for both charging and discharging regulation by inserting a carbon pile regulator in the shunt winding of the booster.

A carbon pile regulator is shown in Fig. 25, and the wiring diagram in Fig. 26.

The carbon regulator consists of two or more sets of carbon disks [C] connected sometimes like a Wheatstone bridge where the shunt field winding of the booster takes the place of the

galvanometer. There is a pivoted lever over the top of the piles, arranged so that by changing its position a different pressure is brought to bear on the various piles which causes their resistances to vary. The lever is moved by a solenoid-actuated iron core, whose solenoid is in series with the generator circuit. A spring at the end of the lever opposes the action of the solenoid. At the required average load the pres-

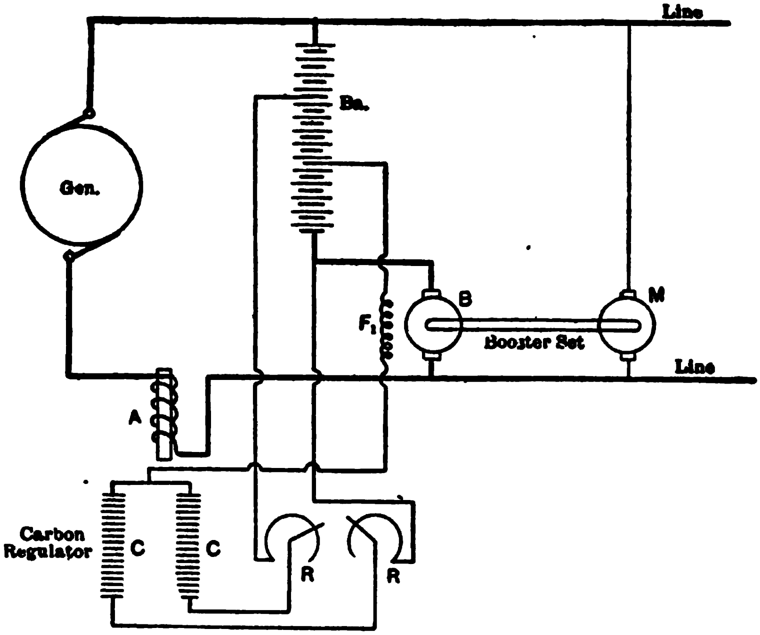


FIG 26.—Diagram of Connection of a Booster Controlled by a Carbon Pile Regulator.

sure on both piles is the same. The ends of the carbon piles are connected to a group of battery cells whose middle point is joined in series with the booster field and to the movable arm on the carbon piles. When the pressure is the same on both piles, their resistances are equal, and there is no current in the shunt winding F_1. But when the current in the main circuit decreases or increases, one of the piles is compressed more than the other, and there is current through the booster field in one direction or another, which causes charging or discharging of

the battery. The piles are set for the required load by adjusting the spring at the end of the pressure arm.

Instead of making the regulator regulate the booster field directly, an exciter may be put between them whose field is influenced by the regulator. The advantage consists in the decreased energy loss resulting from the use of the smaller sized machine. This type of regulator is made by the Electric Storage Battery Co. It is mounted directly on the switchboard, with the carbon piles and spring in front, and the solenoid in back of the board. The solenoid is in the busbar circuit. With the help of this regulator it is possible to adjust the sensitiveness of the charging side relative to that of the discharging side and *vice versa*. In central and sub-stations, for instance, it is sometimes desirable to utilize the overload capacities of engines, generators, converters, etc., but as soon as the load drops under a certain limit, the battery comes into action. With these regulators, also, a zone of non-regulation may be created, extending a certain percentage above and below the average load, whereas, for loads above and below this, regulation may be as perfect as possible.

In the last three years, storage batteries have found a new field of usefulness, which promises to become of great importance in the near future. This is as equalizer in a.c. stations, or in a.c. services.

For this purpose the batteries may be connected up as follows: A number of small series transformers are built into the line to be regulated, whose secondary current is converted into direct current by means of a synchronous rotating rectifier. This direct current, which is proportioned to the watt-component of the alternating line current, excites the field of a counter e.m.f. generator, whose armature winding is in series with the booster field winding and which opposes the voltage of the d.c. buses.

Fig. 27 is the diagram of connections. The battery current called for by the increased load on the line is made to supply the a.c. transmission line by means of an inverted converter. When the external load decreases, the battery is charged through the converter.

Another method is to use the carbon regulator with its solenoid in the a.c. circuit. The batteries and boosters are

joined to the d.c. feeders of a motor-generator set composed of a synchronous motor and a d.c. generator. At low load the generator is used to charge the battery, and when the load rises over a certain amount the motor-generator is reversed and is fed by the battery.

By using batteries in a.c. systems the speed of the machines, and hence the station voltage, are maintained constant. In a.c.

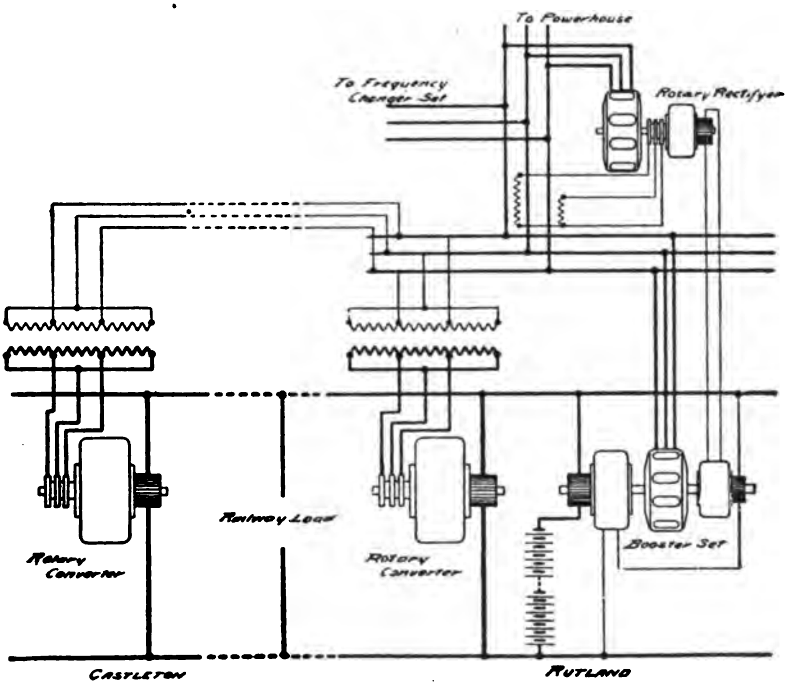


FIG. 27.—Diagram of Connection of a Storage Battery in Alternating-Current System.

lighting systems this results in efficient voltage regulation. By taking up peak loads in this way, the station generating power is increased.

The rating of the battery is the amount of electricity delivered at a certain rate measured in ampere-hours. The rating of a cell varies according to the time and rate of discharge. A cell which has a rating of 100 per cent., for example, at 8 hours discharge will have a rating of only 50 per cent. if discharged in 1 hour. Batteries are usually rated on an 8-hour

discharge basis. For electric automobiles the rate basis is 4 hours, and for railway sub-stations 1 hour.

The following table gives the relative ratings, end voltages, and current values of a cell for different rates of discharge:

Hours Discharge	Final Voltage	Rel. Value of Current	Rel. Rating in amp.-hr.	
8	1.75	1	8	(100 per cent.)
3	1.70	2	6	(75 ")
1	1.69	4	4	(50 ")
$\frac{1}{3}$	1.40	8	$2\frac{2}{3}$	($33\frac{1}{3}$ ")

CHAPTER VI

THREE-WIRE SYSTEM

The so-called three-wire system is used in electric lighting and traction when it is desired to use a current of higher voltage with the same equipment as ordinarily used with low voltages. The principles underlying this system are as follows: The potential difference between the two outside wires is higher than the normal service potential, being usually twice as great as the latter. The lamps and motors are, however, connected between one of the outside wires and the inner wire, called the neutral. The potential between the outer wires and the neutral is equal to the normal service tension. In traction service it is usual to employ the track as the neutral. In this case the saving in copper is comparatively small. The ratio of copper weight for a double track 5000 feet long, using 500 volts, to the same track using 1000 volts, three-wire system, is as 13 is to 11. In lighting systems the saving in copper is much greater, amounting to from 62.5 per cent. to 69 per cent. It admits of the use of both 220-volt and 110-volt apparatus on the circuits. The three-wire system can be built up in different ways:

1. Two generators (Edison three-wire system).
2. One generator with compensator.
3. One generator with balancer set.
4. One synchronous converter.

1. The Edison system is based on two generators connected in series. The two outer terminals are connected to the positive and negative busbars, while the two inner ones are connected to each other and to the neutral bus. The switching diagram is shown in Fig. 28. The fields of both generators are controlled separately and the voltage of both sides can be adjusted at will, or the generator can be compounded to give a high voltage on one side, where such increase of voltage is

desirable to overcome the effects of unbalancing. With this arrangement a large amount of power can be delivered to either side of the system and the extreme degrees of unbalancing can be handled for a short time without disturbance of the lamp voltage. The neutral wire is positive or negative with respect to the true neutral, according as the load is greater on the negative or positive side respectively. The diagram shows the connections of one three-wire feeder, one 220-volt and two 110-volt feeders. With installations of two or more pairs of machines, two equalizer buses are required, one each for the negative and positive sides of the machines. The disadvantage of this system lies in the higher cost of two generators and their

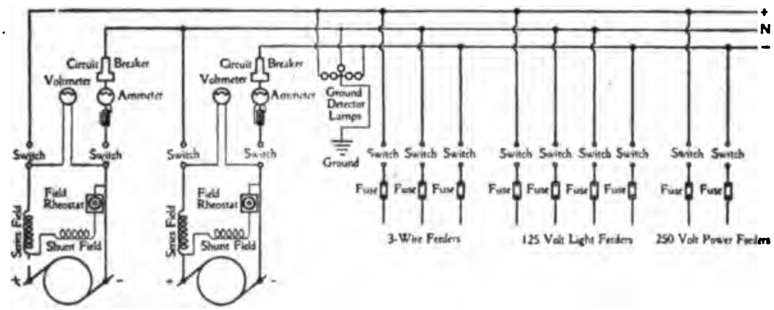


FIG. 28.—Wiring Diagram of an Edison Three-Wire System.

lower efficiency, as compared to a single generator of equal capacity and higher e.m.f.

2. One three-wire generator with compensator. The generator is compound wound, with two series windings, and one shunt field winding. The two series windings are necessary in order to secure with unbalanced loads a compounding approximating that of balanced loads. On the side opposite the d.c. brushes, one or two pairs of collector rings are fastened on the shaft; these are joined to two or four points of the armature winding respectively 180° or 90° apart. The collector rings are connected with a compensator, from whose middle point a wire leads to the neutral. (See Fig. 29.) The action of the machine is as follows: With balanced load there will be only the exciting current through the compensators, which are simply auto-transformers. This exciting current is alternating as the relative potential of the taps to the armature

changes from positive to negative. With an unbalanced load, for example, there being a greater load on the positive than on the negative side, the excess current will return by the neutral wire, and divide in the auto-transformer, returning to the armature through the collector rings. A circuit breaker and an ammeter are installed on either side of the machine. It is advisable to mount the former near the generators, for in this installation they are closed and tripped electrically from the main switchboard. The equalizer switches can also be mounted

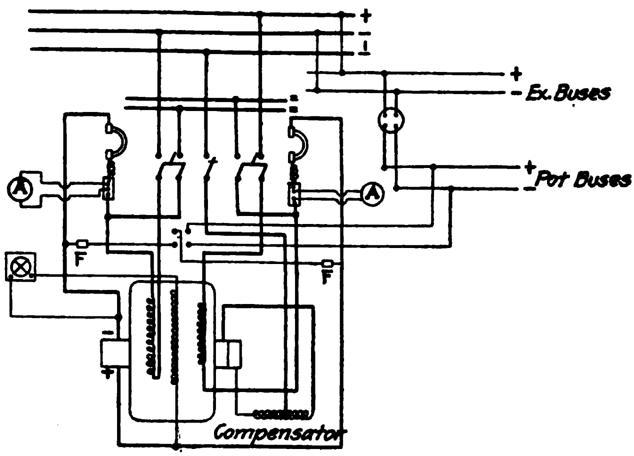


FIG. 29.—Wiring Diagram of a Three-Wire Direct-Current Generator.

near the machine. Such an arrangement affords a saving in copper. The machine is started as follows:

1. Close the equalizing switches.
2. Close the main switches on the switchboard.
3. Adjust the voltage and close the circuit breakers by means of the control switches on the switchboard.

3. Generator with balancer set. For a system which requires more energy than can economically be furnished by the Edison system, one generator of normal e.m.f. equal to that between the positive and negative busbars is used in connection with two motors, which are connected to each other in series, and to the buses in multiple. The connections are shown diagrammatically in Fig. 30. The neutral wire is connected with the common terminal to both motors. When the system is bal-

anced the set operates as two motors, and as motor-generators when the system is unbalanced. The neutral current is unequally divided between the two machines.

"If there is an excess load on the positive side of the system, the e.m.f. between the positive and neutral will be less than between neutral and negative. The negative balancer will tend to speed up and will drive the other as a generator. The unbalanced current will divide, part going to the motor balancer to afford the power to send the rest through the generator balancer back to the line. The series winding of the former tends to weaken the field and increase the speed, while that of the latter assists the shunt winding and raises the voltage

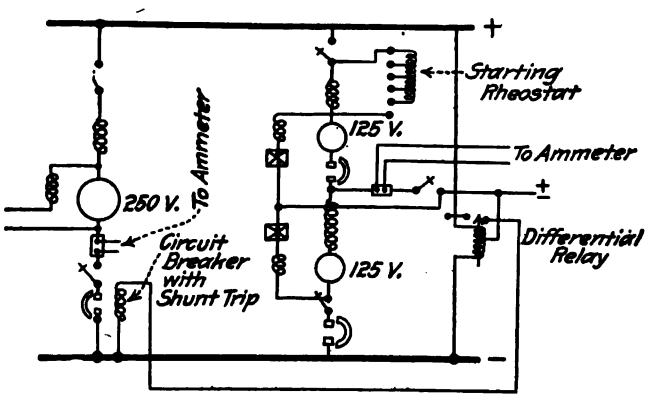


FIG. 30.—Wiring Diagram of a Three-Wire System with Balancer Sets.

across the generator. If the excess load be on the negative side, the positive balancer becomes the motor, the negative balancer, the generator. It is evident that these machines do not add any power to the system, but serve only to balance the load on the two sides." *

Each balancer should have a capacity equal to one-half the maximum unbalanced load that is considered probable to occur. Both machines can be independently adjusted so as to give any desired division of voltage between the sides, and each of the machines can be compounded in such a manner that it will compensate for inequalities of line losses and

* W. H. Peck, "Modern Practice in Switchboard Design," *Electric Journal*, 1905.

natural drop, when the system becomes unbalanced. The shunt windings of both machines are connected in series, and the middle point is joined to the neutral. The generator and the motors each possess a circuit breaker and the necessary main switches. Fuses can be used to replace the circuit breakers of the motors. Both motors are started by means of a starting rheostat. The method of procedure is as follows: In the first place the generator is started in the usual way, and is thrown on the busbars. Then both machines are started together as motors by means of the starting rheostat. When both have reached normal speed, the connection to the neutral is closed, which also throws the shunt windings on to the neutral. Care should be taken not to connect the shunt windings to the neutral when starting. To protect the lamps, etc., against short-circuiting on one side or in case of accidental disconnection of the balancer set, the circuit breaker of the generator is tripped by a differential relay. This relay will trip the circuit breaker in the event of an abnormal rise of potential on either side of the system.

4. Another method of supplying the neutral current is to operate a small synchronous converter as a direct-current motor from the outside conductors, the neutral being connected to the middle point of the compensator operated from the collector rings of the converter. The converter replaces the balancer set.

Where synchronous converters are used to supply a three-wire system, the neutral can be taken either from a common connection of the transformer secondaries, or from a compensator connected to the alternating leads.

CHAPTER VII

FEEDER PANELS

Up to this point we have treated only the methods of generating d.c., and the standard panels controlling the output. Generators, converters, or storage batteries can be used to produce current either independently, in groups composed of like machines, or in mixed groups. This depends upon the number and size of the units and the size and character of the load. We are here concerned with the methods of feeding and the control systems for consumptions of different characters.

Fig. 31 shows switchboard wiring diagrams for d.c. feeder panels for railway service. The positive bus mentioned in former chapters, mounted on the back of the board, is identical with the one here shown. In Fig. 4 the positive bus is mounted on the machine, and therefore requires a special cable to connect it with the positive bus on the feeder panel. Three kinds of feeder panels are shown. Fig 31-A is a panel controlling one feeder and hence is equipped with one circuit breaker, one ammeter with shunt, one kicking coil as lightning protector, and one lever switch. Fig. 31-C is a panel controlling two feeders. The equipment is the same as in Fig. 31-A, with the exception that there are two lever switches in place of one. Fig. 31-B is for two feeders with a double equipment of ammeters, kicking coils, and main switches. A modification of Fig. 31-B has only one ammeter, which is common to both lines. In all three cases when the feeders leave the station overhead, the instruments are protected by lightning-arresters. Fig. 32 shows front views of the three main types of panels and a rear view of Fig. 31-B. The same conditions which applied to panel mounting, busbars, and instrument connections for generator panels, also apply here. We thus have feeder panels where both positive and negative cables are supplied with energy from the board, corresponding to generator panels with both busbars mounted on the board. Such panels are generally used

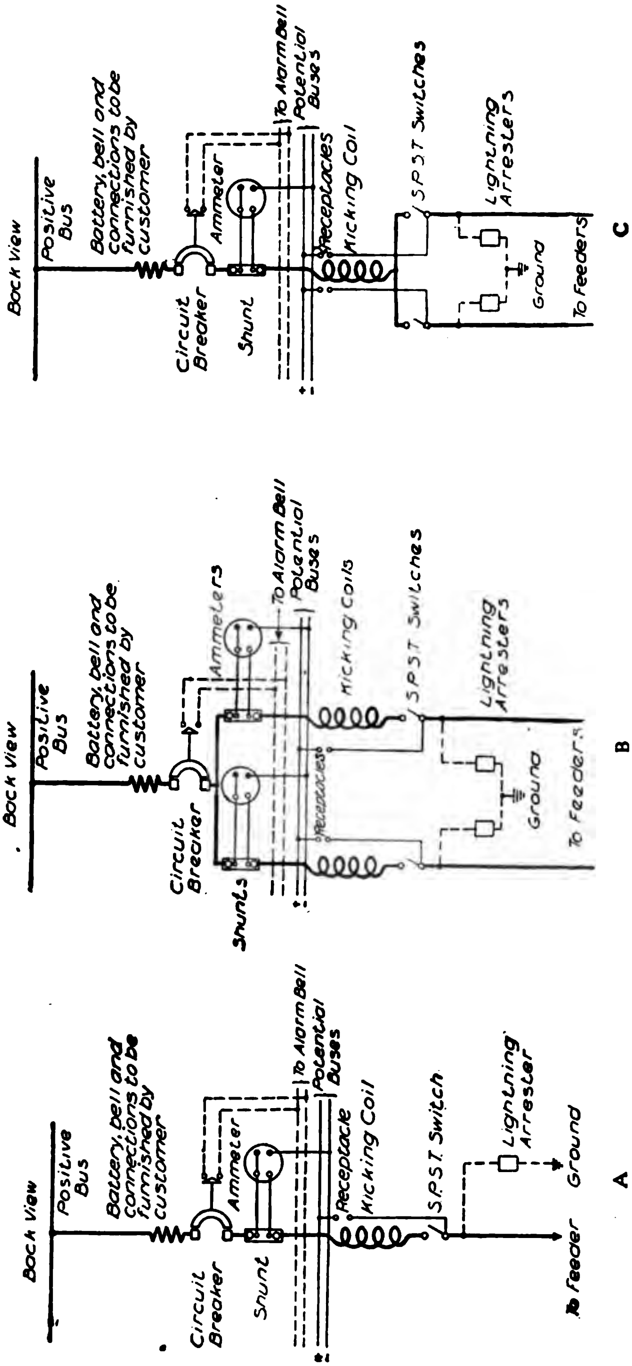


FIG. 31.—Diagrams of Connection for Direct-Current Feeder Panels.

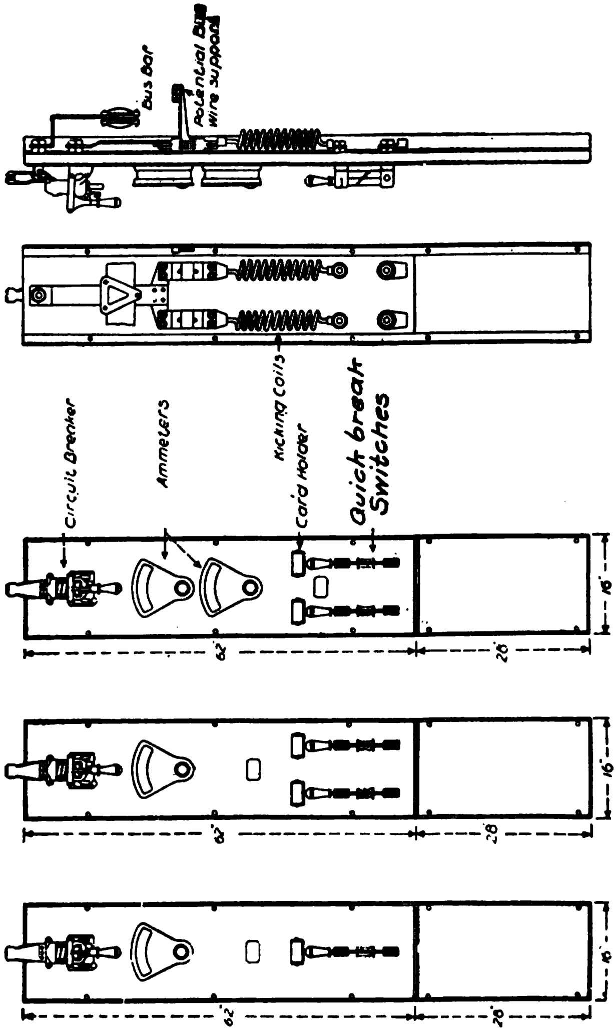


FIG. 32.—Feeder Panels.

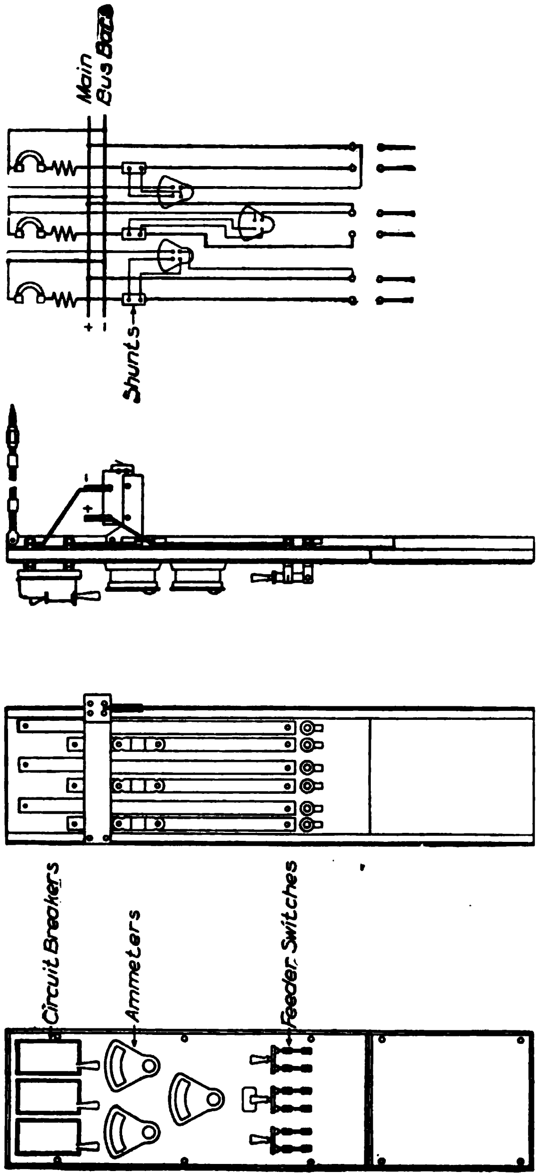


FIG. 33.—Two-Wire Feeder Panels for 125 and 250 Volts.

for voltages of from 125 to 250 for lighting purposes and power distribution. Each panel controls two, three, or four sets of outgoing feeders, and is supplied with the requisite number of circuit breakers and double-pole lever switches. Besides the above-mentioned instruments an ammeter may be supplied for each feeder set, and the voltage of all the feeders may be indi-

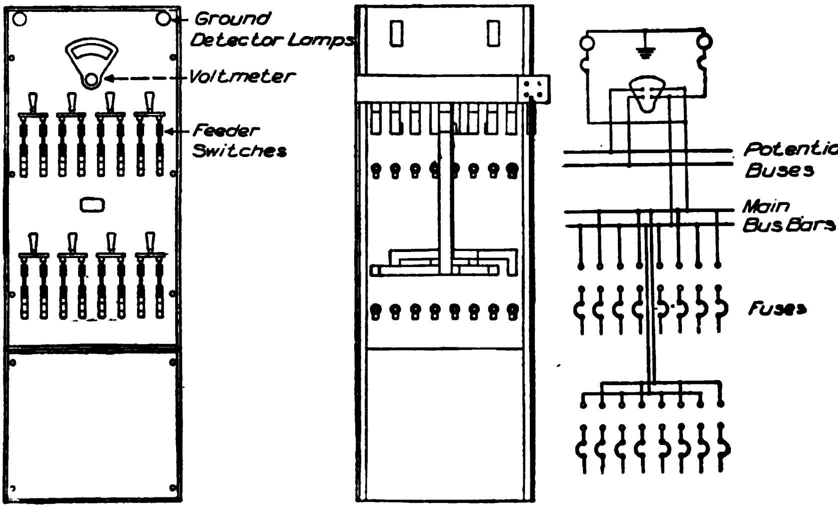


Fig. 34.—Two-Wire Feeder Panels with Fuses for 125 and 250 Volts.

cated by a single voltmeter. (See Fig. 33.) Fuses can be used for feeders of smaller capacity in place of circuit breakers, to insure against over-load. In this case each panel is capable of controlling a larger number of feeders. The fuses are mounted either on the front of the panel with the lever switches (see Fig. 34) or on separate slate bases on the panel rear.

CHAPTER VIII

DIRECT-CURRENT MOTORS

The amount and distribution of the energy as supplied to the line by the central or sub-stations, are controlled from the feeder panels. (See Chapter VII.) The consumption of energy by the individual customers is regulated at the various places of delivery. For lighting installations, lever switches with fuses are employed, which are mounted in groups on cabinet panels. One large double or three-pole lever switch controls the mains, while one or more rows of small double or three-pole switches control the individual lamp circuits. The control for traction systems is much more complicated. This is due to the fact that starting, change of speed, direction, grade, and load, as well as operation of numbers of portable motors, require a very involved switching arrangement. The regulation is accomplished by the controller in the hands of the motorman on the car. It is not the province of this book to give a detailed account of switching arrangements for electric cars or locomotives, as we here treat only of stationary arrangements or such as may be considered stationary in service, for example, portable sub-stations. When electrical energy is required to drive a stationary motor, a special switching arrangement is necessary. This is mounted on a panel near the machine. Fig. 35 is a wiring diagram of such a panel, with views of the board (General Electric Company). The negative side of the shunt field winding is connected on the line side of the starting rheostat to give a maximum field current on the motor when starting. By tripping the circuit breaker the field circuit is discharged through the armature of the motor. The low voltage coil of the starting rheostat switch serves the purpose of opening the motor circuit when the source of power is interrupted. The starting rheostat switch arm is not released by the low voltage coil until after the field is sufficiently dissipated, so that destructive arcing will not occur on the switch.

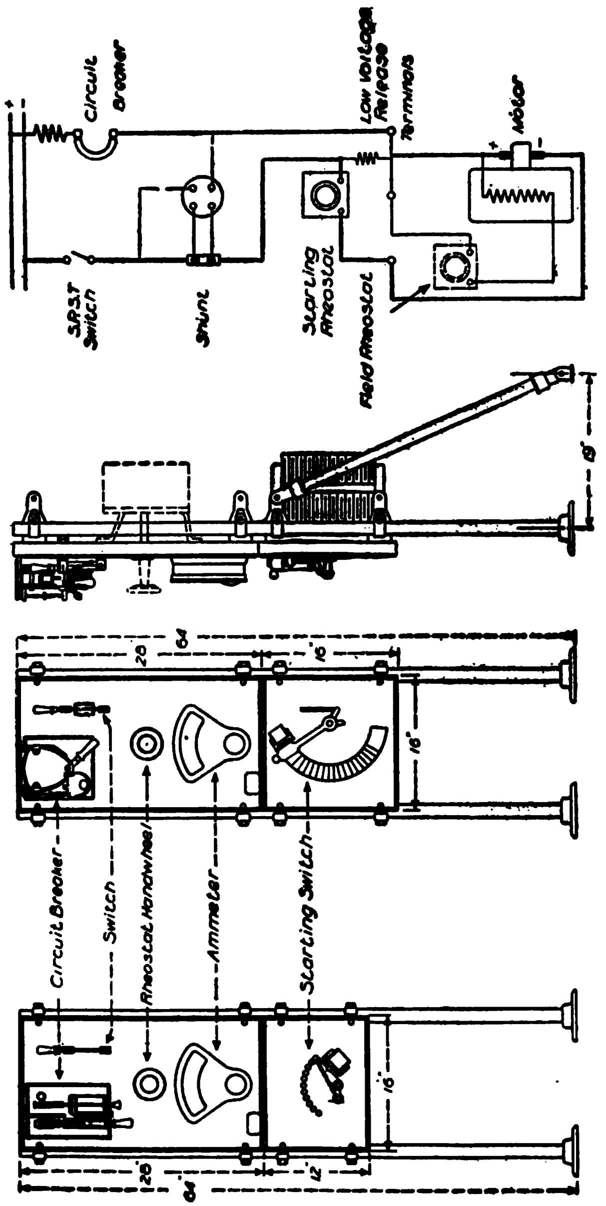


FIG. 35.—Continuous-Current Motor Starting Panels.

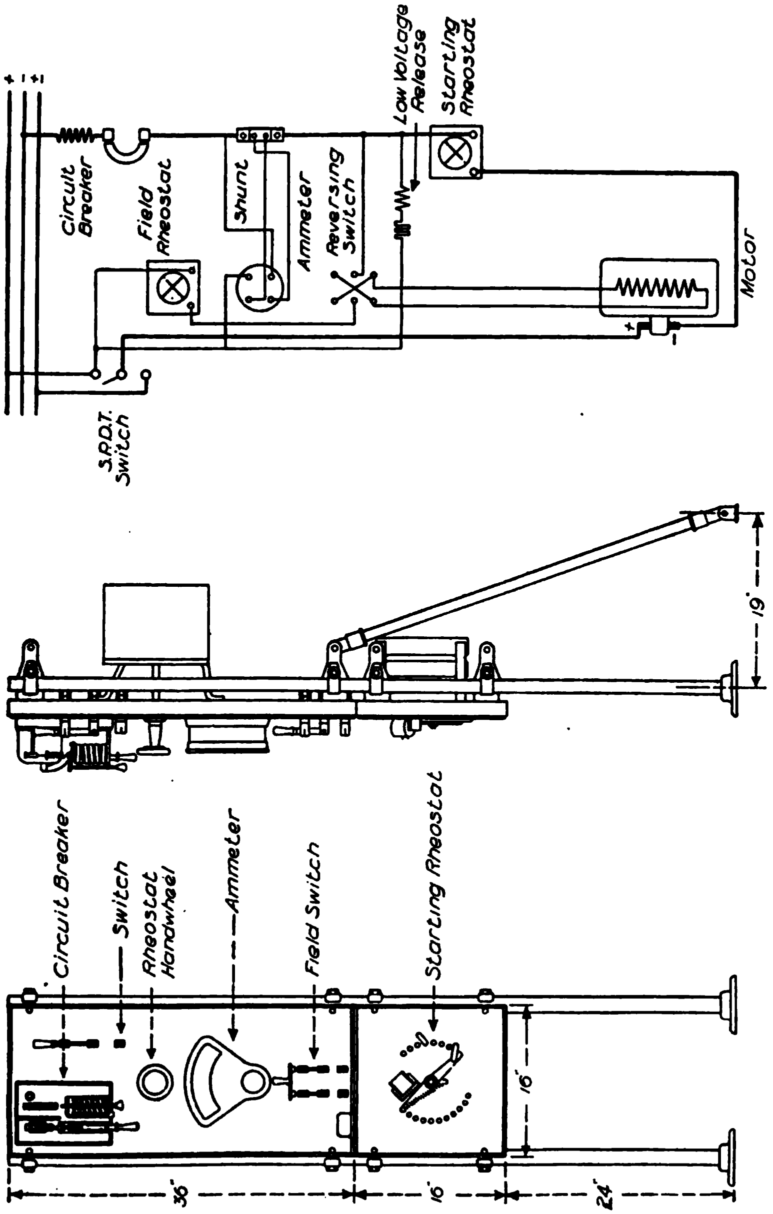


FIG. 38.—Continuous-Current Motor Starting Panels.

When the motor is shut down a spring throws the arms of the switch back to the starting position. The spring also prevents the switch arm from remaining on an intermediate starting point which might result in the burning out of the starting rheostat. This switching arrangement is used for constant or adjustable speed motors, from 3 to 15 hp. 125 volts, or for from 3 to 50 hp. 550 volts. The speed of the adjustable speed motors is regulated by means of a field rheostat shown dotted on the diagram. In place of an ammeter with shunt, a current indicator in series with the circuit can be used wherever minute precision of measurement is not required. Another group of panels comprises those controlling variable speed motors connected to a three-wire circuit, which range in capacity from 2.5 hp. to 20 hp. 125 to 250 volts. The speed of the motors when used with panels shown in Fig. 36 may be increased 400 per cent. above the low speed of the motor. The machine is connected to the 125-volt or the 150-volt of the three-wire circuits by a single-pole, double-throw lever switch. The shunt field winding is always connected to the 250-volt circuit. The field and direction of rotation can be reversed by a double-pole, double-throw switch. However, as long as the motor is in motion, this switch should not be opened. Speed variation is regulated by the field rheostat, which, like the starting rheostat, is mounted on the board. In a modification of this group, the ammeter is replaced by a current indicator. A third group of panels includes those controlling small motors up to 5 hp. 125 volts, 10 hp. 250 volts, and 15 hp. 550 volts. These are constant-speed motors, and are protected against overload by fuses in place of circuit breakers. The panel may be mounted in any convenient place on account of the simplicity of its parts. Frame supports are shown in Figs. 35 and 36.

CHAPTER IX

DIRECT-CURRENT CIRCUIT BREAKERS

We have assumed that the user of this book is familiar with the construction and handling of measuring instruments and the simple forms of lever switches. We therefore treat only of the construction and operation of instruments which embody special features of modern switchboard arrangement. One of the most important pieces of apparatus included under this class is the circuit breaker. This term applies to all devices which automatically interrupt the circuit under special conditions. These conditions are twofold. They depend either on the variation in electrical energy flowing through the circuit breaker or on certain conditions of the machines in circuit, which in turn may produce or be a result of the first. Examples of the first condition are short-circuit, grounding, overload, underload, low voltage, current reversal, and phase reversal with a.c. Running away of an inverted converter is an example of the second condition. In this chapter we will treat only direct-current circuit breakers, which differ materially from those generally used for a.c. The main function of a circuit breaker is to interrupt current rapidly and at the required instant, without injury to itself. When the circuit breaker opens, an arc is formed which keeps up the circuit and is damaging to the apparatus. Devices must therefore be provided to suppress the arc, to divert it from the main contacts, or to blow it out at the instant of formation. The General Electric Company circuit breaker, type C, form K (Fig. 37), is so designed that the arc is diverted to secondary contacts, on top of the breaker, where it is finally broken, thus protecting the main contacts from injury by burning. The auxiliary contacts have carbon tips which are easily renewed. This apparatus is used for heavy service and special railway work. It is made in two styles, one for circuits up to 250 volts, and from 800 to 6000 amp., and one for circuits up to

650 volts, and from 800 to 10,000 amp. The main contacts are bridged by a laminated copper brush, which is pressed against the contacts by a toggle joint. The opening is accomplished through the action of a horseshoe magnet placed around the lower contact stud. A swinging armature on the magnet releases a catch on its upward motion, thus permitting the breaker to open. A flat spring and the weight of the

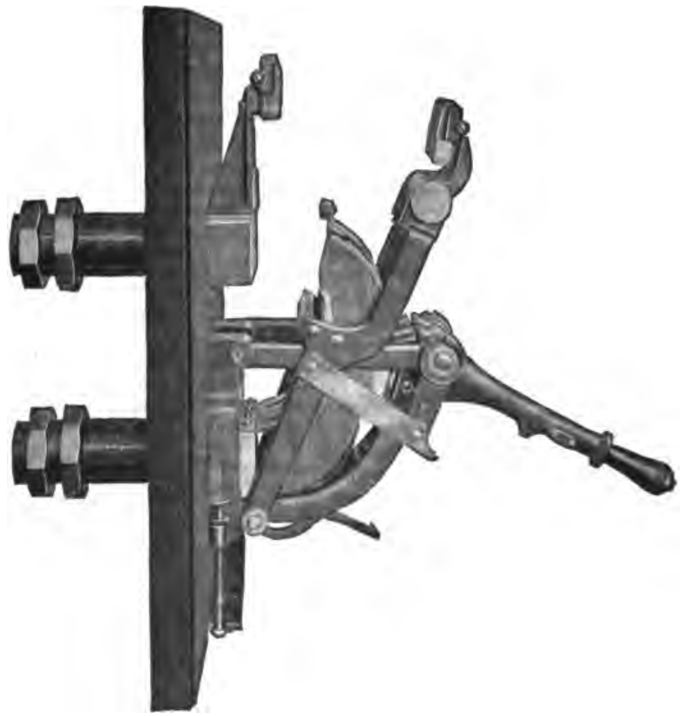


FIG. 87.—Type C, Form K, Carbon Break Circuit Breaker (General Electric Co.).

brushes which are pressed against the contacts, throw the breakers open.

The principle upon which the tripping of a type C circuit breaker of the Westinghouse Company is based is the lifting of a weight against gravity, by the magnetic pull produced by an electric current. The circuit breaker can be adjusted to operate for different current strengths by moving the weight along a graduated scale beam. This adjustment is possible, because

for every displacement of the weight, a corresponding magnetic pull is required, which is produced by different values of the main current. The laminated contact bridge is similar to that of the General Electric Company breaker described above. When the breaker opens the current is gradually shifted through the copper shunts to the carbon contacts, and thus no

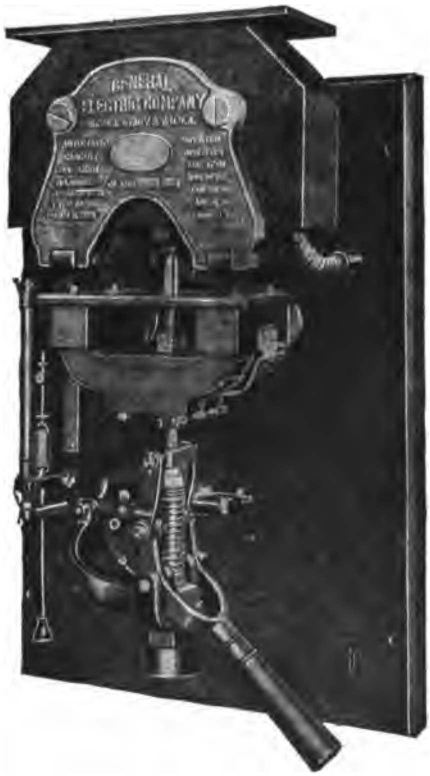


FIG. 38.—Type M, Form K_3, Magnetic Blow-Out Circuit Breaker (General Electric Co.).

arc is formed until the final break takes place between the carbon contacts at the top. Since the arc is blown out in an upward direction, it is advisable to mount the breakers near the top of the switchboard, in order to protect other instruments against damage. These breakers are manufactured by the Westinghouse Company for d.c., as well as for a.c. use. They are built single, double, or triple-pole, separated from

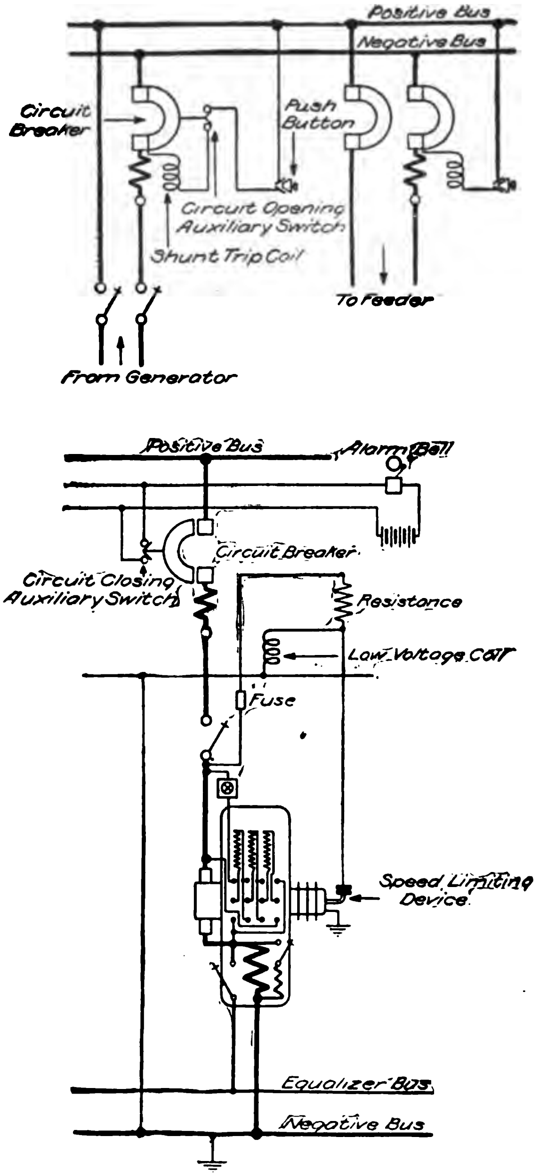


FIG. 89.—Connection of Shunt Trip Coil With and Without Circuit Opening Auxiliary Switch.

each other by marble barriers, and are tripped independently by automatic tripping coils. By means of special devices the tripping coils can be interlocked in such a way that the circuit breakers are closed and opened together, or that the closing is independent and the opening simultaneous. For these breakers, the service voltage should not exceed 750. Fig. 38 shows a General Electric Company circuit breaker, type M, where the arc is blown out at the instant of formation, by means of a magnetic field. This type is recommended for use with generator or feeder panels connected to circuits where violent overloads are frequent. The secondary contacts and the coil

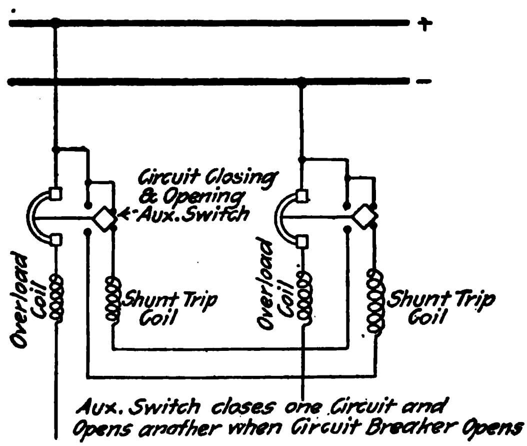


FIG. 40.—Connection for Interlocking Two Circuit Breakers by Means of Shunt Trips and Auxiliary Switches.

of the blow-out magnet are in parallel with the main contacts. Owing to the comparatively high resistance of the secondary contacts there is practically no current through them until main contacts open. Then the whole current is shifted to the magnet coils, and the strong magnetic field extinguishes the arc as soon as it is formed on the secondary contact. The secondary contacts and coil are inclosed in a fiber box over the main contacts. The laminated copper contact bridge is pressed against the main contacts by a toggle joint. The tripping is accomplished by means of a horseshoe magnet, which encircles one of the main studs on the rear of the panel. Its action is similar to that of the breaker first described. When

the breaker is released by the armature of the magnet, the bridge is thrown open by the action of a spiral spring and its own weight. This type is adapted to 650 volts and from 3000 to 10,000 amp. Several other forms of breakers of the types mentioned are on the market, corresponding in their construction to the various requirements of current, voltage, and character of service. In most of these forms the tripping coil is in series with the line which is to be protected. All of the breakers are constructed so as to interrupt overload. Through additional devices they may be tripped also at low load, or low tension. They can also be operated by push button from any

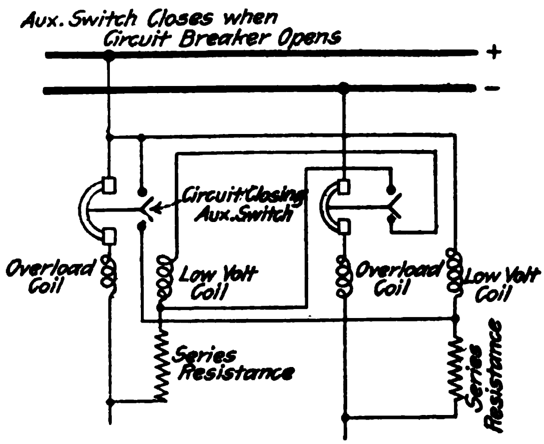


FIG. 41.—Connection for Interlocking Two Circuit Breakers by Means of Low-Voltage Releases and Auxiliary Switches.

given place, or they may be tripped together. Figs. 13 and 14 show the switching arrangements for the low-voltage release of the breaker connected with the speed limiter of an inverted converter. Its object is to trip the circuit breaker when the line voltage drops to 50 per cent. or less of the normal pressure. It also performs the function of a shunt trip when used in conjunction with a push button, auxiliary switch, or speed-limiting device. Fig. 39 shows the diagram of a shunt trip with and without circuit-opening auxiliary switch. It can be operated by means of a push button from any desired point. At the moment of opening of the circuit breaker, the auxiliary switch opens the shunt circuit. Closing auxiliary switches are

also constructed, built on the same lines as opening auxiliary switches. They are used for closing tell-tales or signal lamp circuits at the instant of main current interruption. (See Figs. 1, 5, 13, and 14.) Circuit closing and opening auxiliary switches are employed when two or more breakers are interlocked, these being used for simultaneous operation. (See

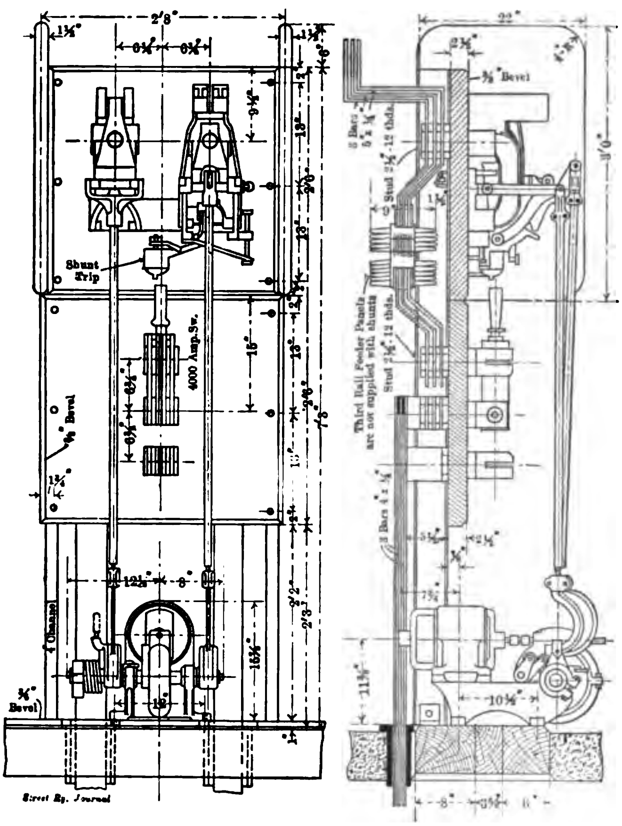


Fig. 42.—Motor-Operated Circuit Breakers.

Fig. 40.) At the moment of tripping of the circuit breaker, the auxiliary switch interrupts the circuit of its own shunt coil, but closes that of the second circuit breaker, thus causing the circuit breaker to be tripped. Fig. 41 is a similar diagram of two interlocked circuit breakers with the use of circuit-closing auxiliary switches and low voltage coils.

The line is protected against current reversal by a reverse current relay in the breaker. These relays are especially necessary when storage batteries supply the line in conjunction with a motor-generator set, or synchronous converter. They prevent the batteries from delivering energy back into the motor-generator set or converter in case of disturbance on the high-tension side. This type of relay consists of a horseshoe magnet encircling one of the contacts of the circuit breaker. A movable armature connected to the busbars is inserted between the poles of the magnet. With normal current direction the armature will move in one direction. A stop is provided to prevent movement beyond a certain point. By reversal of current the armature revolves in the opposite direction, which closes the shunt-winding circuit, thus tripping the breaker. For large currents, electrically operated, circuit breakers are used. In the Westinghouse apparatus, two coils are provided in connection with a plunger, one for opening and one for closing. The General Electric Company employs a solenoid or a reversible electric motor to operate the breaker. Fig. 42 shows the arrangements for two circuit breakers for 4000 amps. operated by an electric motor. Both breakers are connected in series with each other, and with a single-pole, double-throw switch. The opening and closing are simultaneous. The double-throw switch is operated by the same motor, and is shut down only after closing of the circuit breaker, so that in case the feeder is closed on a short-circuit the breaker can immediately open. The arrangement described is that used by the New York Central Railroad Company in their circuit breaker sub-stations.

CHAPTER X

DIRECT-CURRENT STATIONS

We will use this term to include only those direct-current plants where natural or derived mechanical energy is converted into electrical energy. Converter stations do not come under this heading, inasmuch as they interconvert the different forms of electrical energy only. Direct-current stations are constructed to furnish energy for traction, for stationary motors, for lighting systems, and for chemical or metallurgical purposes. Plants for power and lighting are often built in one, while traction plants may also be used for different classes of work. Direct-current stations are not used for high-tension transmission systems in this country. European exceptions to this rule are the Thury d.c. transmission systems, for example, St. Maurice-Lausanne operating at 27,000 volts, and Mountier-Lyon at 57,600 volts.

TRACTION

Direct-current central stations for from 550 to 650 service voltage are profitable only when the traction system is confined to a small area, and when it is possible to locate the power house at or near the load center. The reason for this is found in the fact that for larger systems the cost of copper for feeders materially increases the first cost, thus making the investment unprofitable. We therefore see that 600-volt d.c. stations are limited to small street railway systems or to isolated traction systems for industrial purposes. When a system has outgrown the area for which the plant was originally designed, independent plants may be added to supply the different sections. The choice between adding independent stations or changing the method of supply to another system depends upon conditions.

When the service voltage is doubled (say to 1200 volts), the economic limit of operation is correspondingly increased.

After the characteristics of the proposed line are known such as length, direction, curvature, and grade, the next duty of the engineer consists in determining the average load in different sections of the line, from known data as to size, occupation, and shifting of the population of the adjacent territory. From these points he is enabled to fix upon the load center of the average load. Since the load center determines the minimum weight of copper necessary for feeders, the advantage of locating the power house at this point is evident. Value of real estate, proximity of water and coal supply, and methods of feeder installation must naturally be taken into consideration. The feeder system is calculated and distributed after the maximum load of different parts of the line or the load variation per day and per season have been determined. All of these calculations and estimates serve to fix the number and size of the power units in the central station. The location of the power house is often predetermined by the proximity of water power to the system. Other sources of power must often be added to that afforded by water power in order to meet the requirements of the service. The size of the building is completely determined by the number and size of the generators, by the choice of motive power, and by the estimated expansion necessary in future time. The portion of the building with which we are concerned is that part which is reserved for the installation of generators, auxiliary electric machines, switchboards, and cables. In practice, the electrical engineer must work hand in hand with the mechanical and civil engineers and architect. In d.c. central stations the switchboard, which is generally a direct-control board, is located in a place whence the operator can easily overlook all the machines. It is therefore placed in a gallery at one end, or along one of the main walls of the machine room.

HIGH-TENSION TRACTION

The recent tendency has been to increase the service voltage. This tendency is advocated by Mr. Frank J. Sprague (*Str. R. J.*, Dec. 23, 1905), Mr. Hobart (*Electrical Review,* London, Vol. 46), and Dr. Louis Bell (" Power Distribution for Electric

Railways"). The following paragraphs sum up the arguments in favor of the high-tension current brought forth by the above-mentioned engineers:

One of the most important factors in the investment and cost of operation for an electric traction system is the value of copper in the feeders and trolley wires and the drop in voltage due to their resistance. With a given service voltage, as for instance, 550, a certain drop in the line and a corresponding minimum cross section of feeders is permissible. Any extension of the service area or load will cause an increase of drop in voltage, which must be compensated for by allowing a larger cross section of feeders, or by the use of additional feeders. This increase in copper weight can be avoided by increasing the service voltage, thus decreasing the current.

The weight of copper varies inversely as the square of the voltage. That is, if we double the voltage from 500 to 1000, a line four times as long can be supplied, using the same amount of copper, and allowing the same per cent. drop. The actual results are slightly better even than these figures indicate, since the track return gets relatively better and better as the voltage rises and the current diminishes. A larger percentage can therefore be allowed for the copper line drop. This matter is of even greater importance for a.c. central stations and d.c. sub-stations. (See Chapter XXV.) For voltages between 750 and 1000 the construction of generators of less than 1000 kw. rating is entirely feasible. If the cost of one large machine should be too great, this machine may be replaced by two smaller ones of lower voltage connected in series, or by two synchronous converters. The increased voltage may also be obtained by making use of a booster, as will be explained later. The motors used for this system are also easy to construct, a 650-volt machine is guaranteed for 750 volts. The motors used for the Berlin Elevated System, and for the Interurban Railway of Zweisimmen-Montreaux, are built for 800-850 volts, but are actually wound for 1000 volts. By a series-multiple connection, motors for 500-600 volts can be used in 1000-1200-volt circuits. There are seven railway systems in the United States which now employ or contemplate employing a direct e.m.f. of 1200 volts.

LIGHTING SYSTEMS

The economic considerations involved in this class of plants are similar to those discussed under traction systems. Small system d.c. stations are built at the load centers. They are often called upon to supply energy for motors, for which purpose separate machines are sometimes used. If the number of units for various purposes is increased above a certain point, the efficiency of the station will become less than would have been the case had the small generators been replaced by a few large a.c. machines used in conjunction with converters. The most common case where d.c. is used for lighting is that of isolated plants, for office buildings, theaters, hotels, etc. Such plants are of the most economical form, because they are located near the receiving apparatus, and the cost of wiring is therefore reduced to a minimum. Besides supplying energy for the lighting system, the plant also supplies energy for elevators, fans, and other light machinery. The predominating system for light and power distribution is the three-wire system. Where higher voltage for certain purposes is not obtainable with this system, separate units must be used, as mentioned above.

CHAPTER XI

TYPICAL ELECTRIC POWER STATIONS

MEMPHIS STREET RAILWAY COMPANY (TENNESSEE)

THE power house is an old building with an annex of modern construction. In this annex is installed a 2000 kw. G. E. generator, driven by an Allis-Chalmers vertical two-cylinder, cross-compound engine of 3000 hp. Fig. 43 shows a load curve of the system, for January 27, 1908. Plans have been made for a further extension to accommodate a second generator of the same type and foundations for a third. Fig. 44 is a plan of the

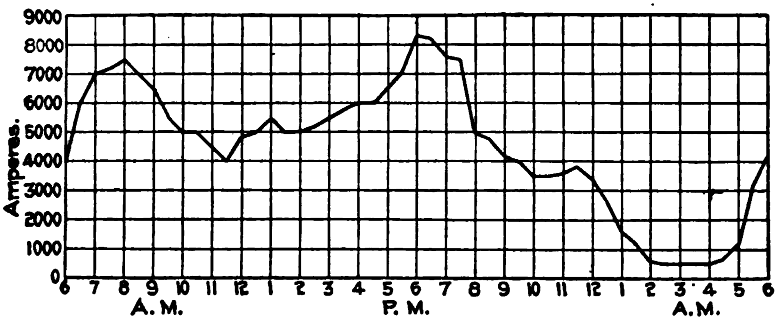


FIG. 43.—Load Curve of the Memphis Street Railway Company's Power House.

foundations of the three engines on whose shafts the generators are mounted. The right wall is that of the old power house, which communicates with the annex by only one door. The plan shows the cable distribution. The positive cables lead from the foundations of the machine where they are inclosed in the ducts, under the engine-room floor, and to the front wall, whence they pass between the windows up to the switchboard gallery. The plan indicates the cable disposition for possible fourth and fifth generators. The negative and

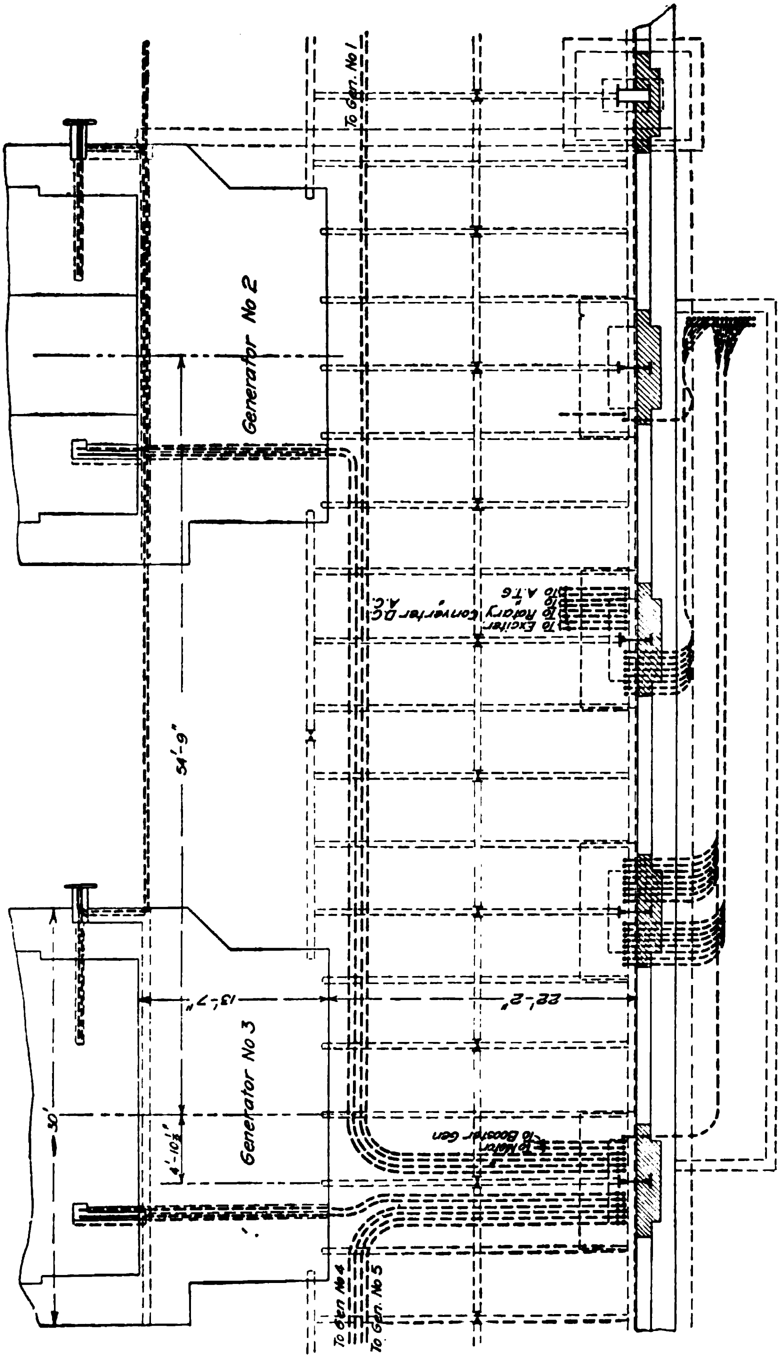


FIG. 44.—Plan of Engine Room, Showing Layout of Generator Cables (Memphis Street Railway Company).

equalizer buses are conducted in tile tubes through the foundations and are connected by means of cables with their proper switches, which are in turn connected with the terminals of the machine by cables running through the foundations. Figs. 44 and 45 also show the manner of conducting the feeders from the main building into the underground passage which runs along the main wall. The feeders are supported on racks in three rows, one on the main wall and two rows on either side of a pipe support in the center of the passage. At the end of the passage the feeders pass through the ceiling to the overhead transmission line. A number of ducts are built into the end of the passageway, to be used in case it is desired to extend the feeders underground instead of overhead. Figs. 46 and 47 show front, rear, and side views of the switchboard and the wiring diagram of the station. The positive bus of the generators is mounted on the board, and the machines are equalized on the negative side. A general output ammeter, a recording wattmeter, and a watt-hour meter are connected with the main bus between the generator and feeder connections. A motor booster set is connected to the buses, whose functions are as follows:

In traction systems the service area sometimes expands to such an extent that there is a considerable voltage loss at the extreme points. This is also the case in systems where at certain points the load rises to an excessive degree. In order to overcome this difficulty, the cross section of the feeder conductors to these points must be increased, so that the voltage drop may be kept under a certain maximum. Several such feeders of large cross section and increased weight are sufficient to add materially to the necessary investment. One of the methods of diminishing the cost due to this source is to increase the initial pressure of the feeder in question to such a point that the resultant voltage will at all times be above the required minimum. The voltage of the generator itself can be raised only to a limited value by means of over-compounding the machine. If this value is exceeded the higher voltage at other parts of the system, as, for instance, near the station, becomes a serious disadvantage. Over-compounding the generator also causes increase in cost. In cases where the probable growth of the system can be estimated, a.c. plants

with converters are often recommendable. However, we have another means at our disposal for raising the voltage of the

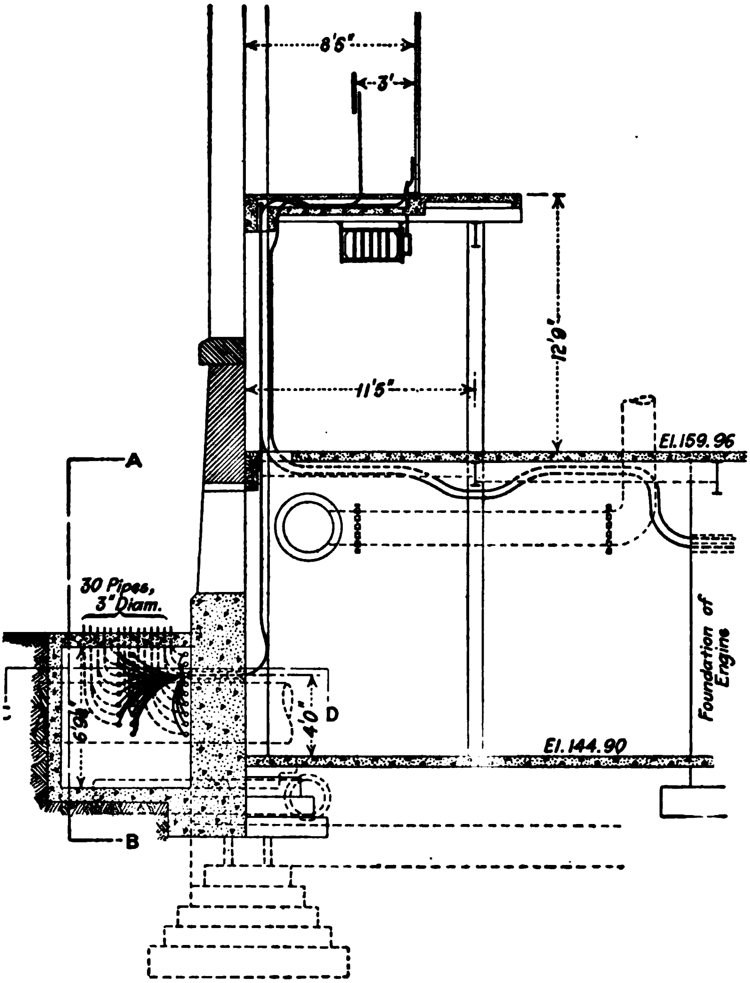


FIG. 45a.—Section through Switchboard Gallery (Memphis Street Railway Company).

system at certain points, or in the whole line, and this is the application of the booster.

Fig. 48 shows a booster in series with the main circuit. The case taken is that of a generator feeding only one main at an

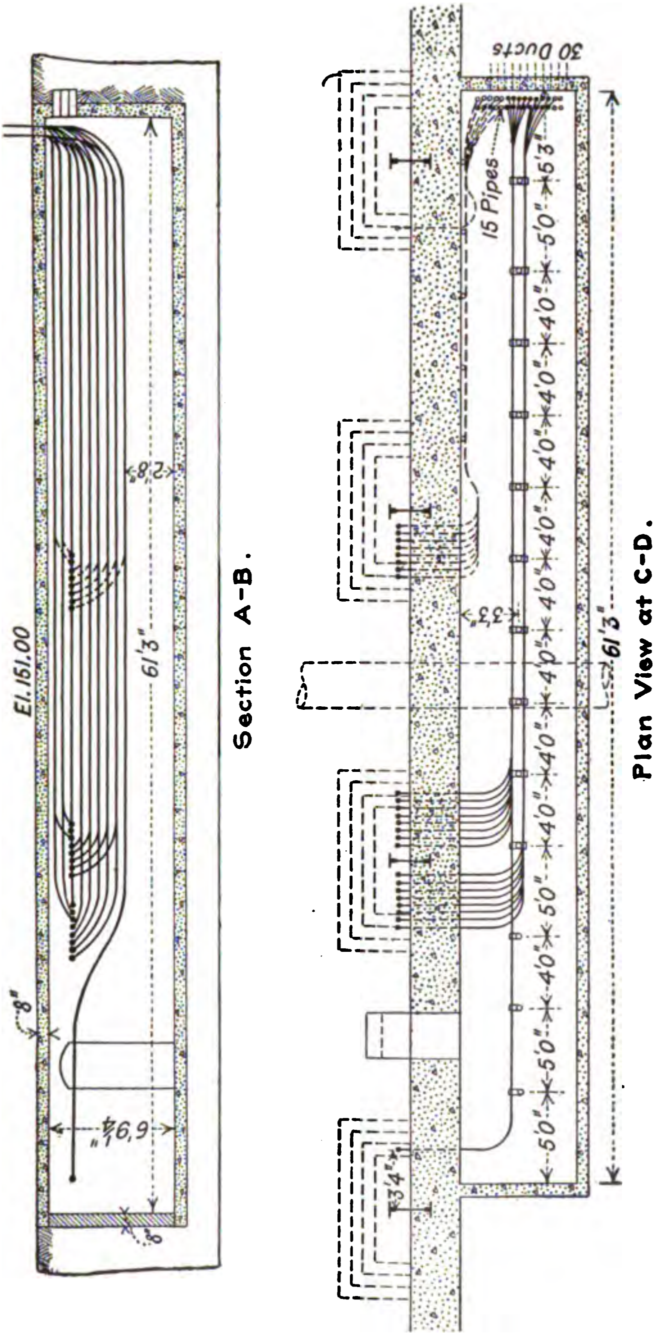


FIG. 45b.—Layout of Cables in Trench (Memphis Street Railway).

e.m.f. of 550 volts. The booster voltage is assumed at 200, and the current at 500 amp., so that the combined voltage amounts to 750. Since the initial voltage is 750 a loss of 300 may be allowed on the line. The reduction in cross section of the feeder thus made possible is considerable when compared with the cross section necessary with an initial voltage of 550, and an allowable drop of 150 volts. This method of allowing the booster to feed directly into the line is economical only when used about three hours per day of service at full load. It is therefore well suited to help over the time of unusually heavy traffic. For, although the initial cost of the booster, which is generally driven by a motor or other mechanical power, is small when compared with the saving in copper, its operation for a larger period than three hours at full load is nevertheless very expensive and uneconomical on account of the energy lost in the line. This machine is used to its best advantage for the independent operation of the special feeders required, not including the entire system. This is the case assumed in Figs. 46 and 47. The booster, which is driven by a d.c. motor, is connected through double-throw switches with five feeders, thus making it possible to feed these cables with either the normal voltage of 600 from the main bus, or the higher voltage from the booster bus. The side and the rear views of the switchboard show the busbar connections and mountings. The four cables of 1,500,000 cir. mils each for each generator, are run up the wall to the gallery floor, where they are laid in brick partitioned channels. (Fig. 49.) They are then connected to the watt-hour meters mounted on separate slate slabs in back of the board. From the watt-hour meters they lead back under the floor to the main switch on the generator panel. The three spaces between the main wall, watt-hour meter panels, main switchboard, and gallery edge are kept to a minimum in order to keep down the width of the gallery, but are nevertheless wide enough to admit a safe access to all parts. The switchboard stands on a wooden block 1 in. above the floor. The channels for the generator and feeder cables are covered with concrete slabs. The positive bus is composed of copper bars 10 in. by 0.25 in., the number of which decreases with the increase in distance from the generator panels, since the amount of feeding decreases as we

recede from the panels. Note the special construction of the gallery floor, which is lowered in back of the board on account of the placing of the cables. The construction is reënforced concrete resting on 8 in. I-beams, four feet center to center, running perpendicular to the main wall. These I-beams are fastened on one side to the crane columns by means of channels, and at the other ends to longitudinal I-beams supported by independent columns. The space between the channels and the masonry affords a passage for the cables leading to the gallery floor. The feeder and positive generator cables are

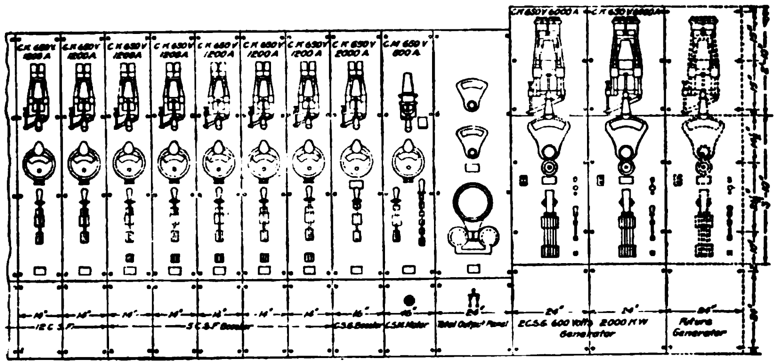


FIG. 46a.—Switchboard, Front View (Memphis Street Railway).

lead covered, and are therefore fastened directly to the wall. All the feeders are 1,000,000 cir. mils for each panel. The negative and equalizer cables are double braided. All the outgoing feeders lead to the above-mentioned underground passageway through ducts built into the concrete foundation of the wall. The passageway communicates with the basement of the engine room by a door towards the end of the passage. The field rheostats are mounted under the floor of the gallery, and are easily operated from their respective boards. The negative bus is made up of 5 in. by 0.25 in. uninsulated copper bars. The equalizer bus is of similar dimensions, but is wrapped with insulation. The method of mounting these two buses between the foundations of the units is shown in Fig. 50.

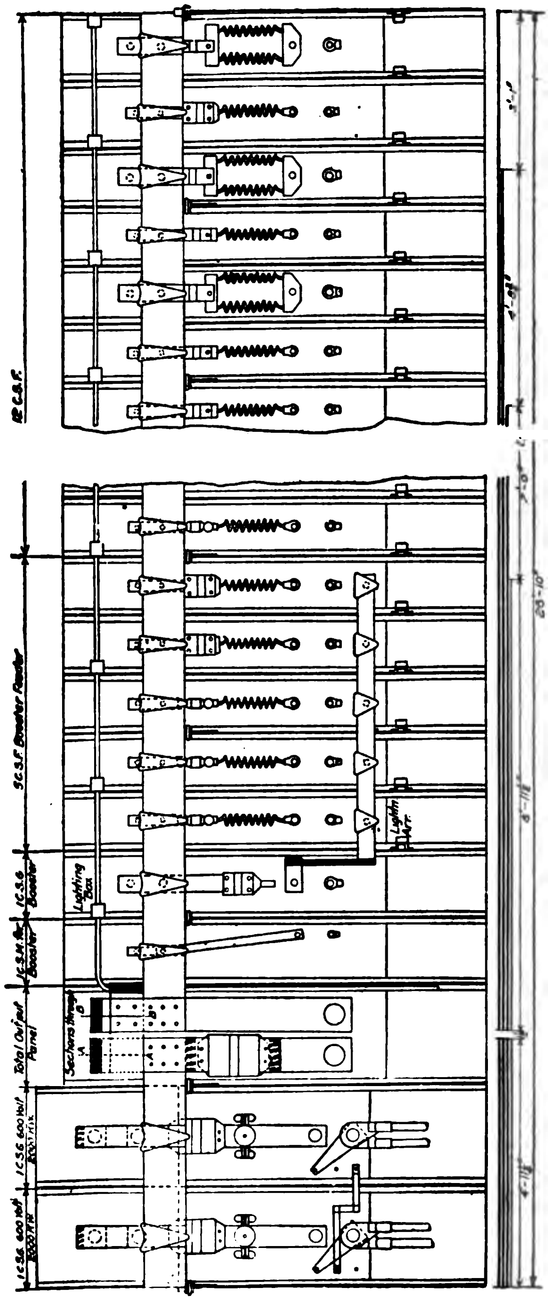
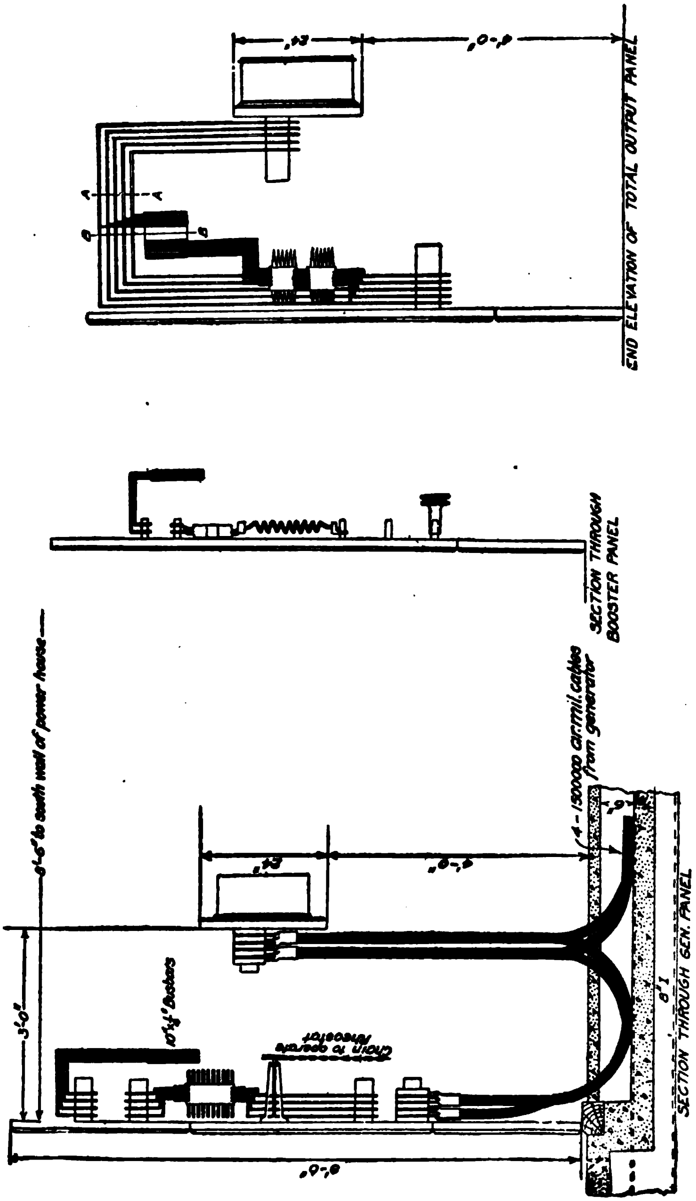


FIG. 46b.—Switchboard, Back View (Memphis Street Railway).



FIGS. 46c and 46d.—Switchboard, Section and Side View (Memphis Street Railway).

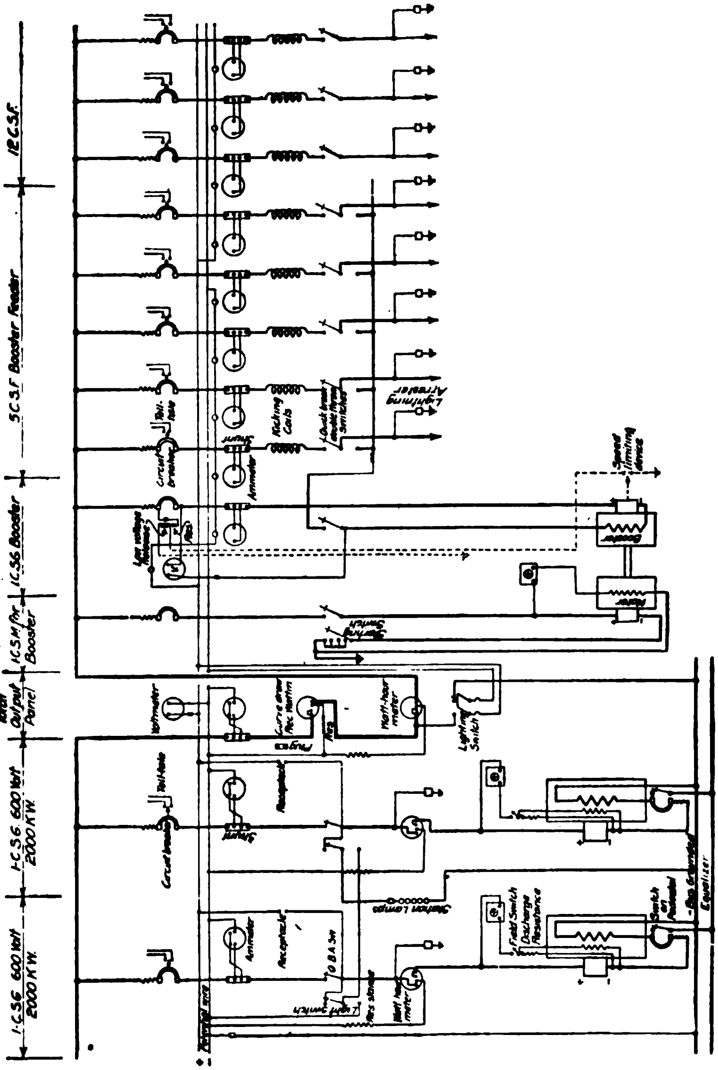


FIG. 47. Switchboard Wiring (Memphis Street Railway).

INDIANAPOLIS AND LOUISVILLE TRACTION COMPANY

(Abstracted from *Electric Railway Review*, Nov. 30, 1907)

The first 1200-volt interurban railway in the United States began operation on November 6, 1907, between Seymour and Sellersburg, Ind., 41 miles apart. The central station is located near the center of the line. The trolley wire of No. 0000 copper wire is fed by feeder cables running 17 miles in each direction from the station. They are made up as follows:

10	miles of	500,000	cir. mils.
20	"	300,000	"
4	"	211,000	"

The electric energy is generated by two units. Each unit con-

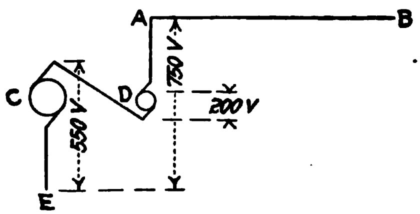


FIG. 48.—Diagram of Booster Connections.

sists of two generators driven by an engine. The generators for each unit comprise two 600-volt General Electric multipolar (type M. P.) units with armatures, mounted commutator to commutator on the engine shaft. Fig. 51 indicates the switching arrangements for both generators of one unit. Their armature coils and series field coils are connected in series as though for one generator. The shunt field for each machine is connected across a circuit having 600 volts difference of potential. Each of these 300 kw. machines is compound wound, having a flat output curve. The switchboard for controlling the output of the two 1200-volt generating units comprises two machine and two feeder panels with two 1500-volt voltmeters on swinging brackets, and a watt-hour meter on each machine panel. For use in the nearby repair shop, and for lighting the power house, 600 volts are obtained by connection between the two machines of one unit. The absence of sub-stations such as are

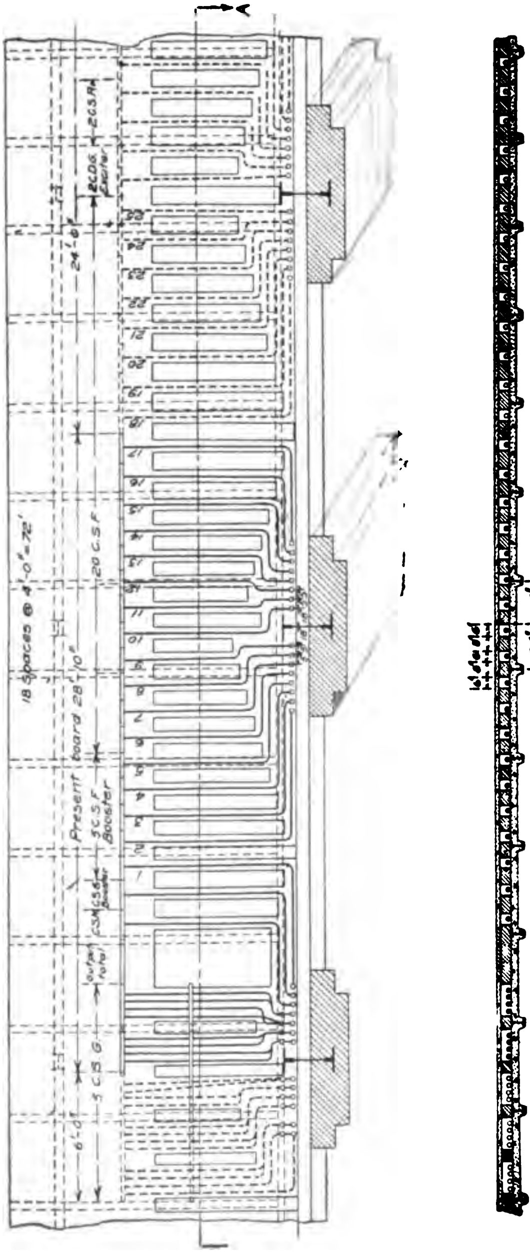


FIG. 49.—Switchboard Gallery Floor Construction.

necessary with a.c. generating stations and of high-tension feeders is an advantage of this system.

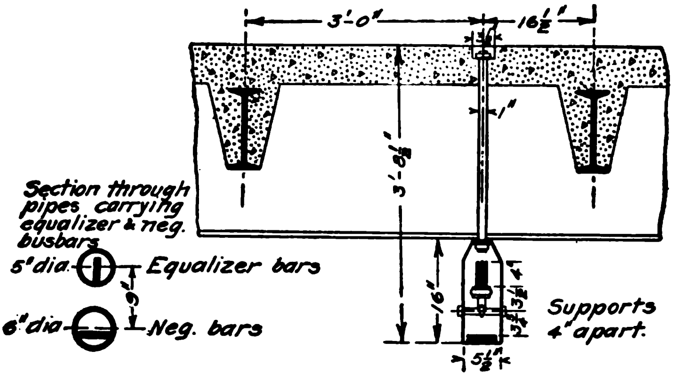


Fig. 50.—Method of Supporting Negative and Equalizer Busbars Between Engine Foundations.

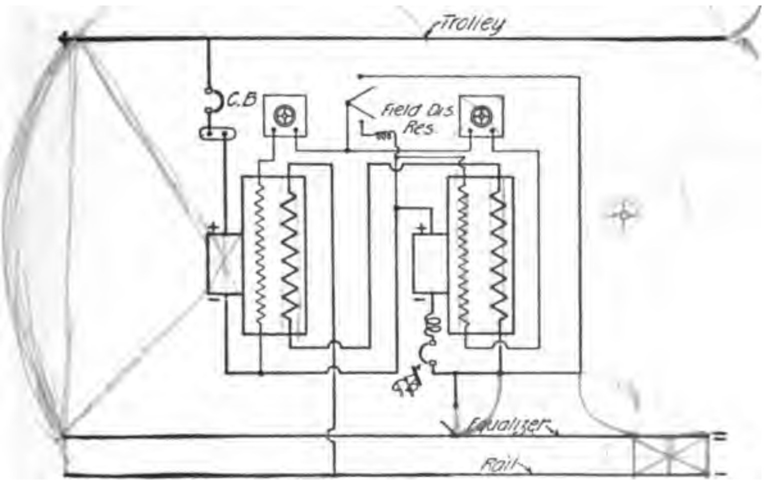


Fig. 51.—Indianapolis and Louisville 1200-Volt Railway: Method of Connection of Two 600-Volt Generators.

LIGHTING SWITCHBOARD

Figs. 52 and 53 show a combined system where an independent generator delivers a 600-volt direct current, and an independent three-wire system is used for lighting purposes.

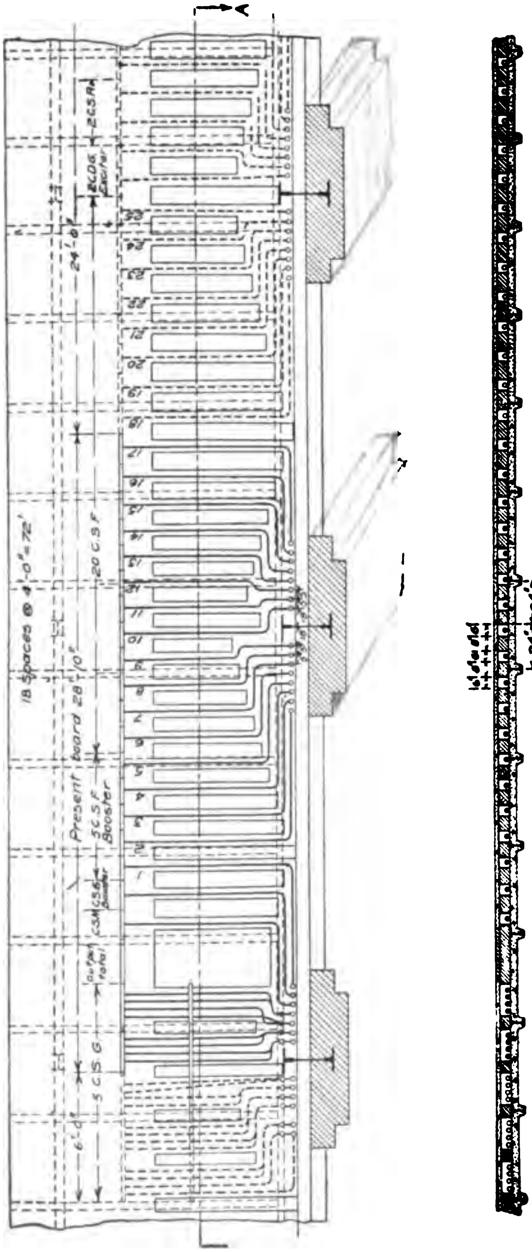


FIG. 49.—Switchboard Gallery Floor Construction.

necessary with a.c. generating stations and of high-tension feeders is an advantage of this system.

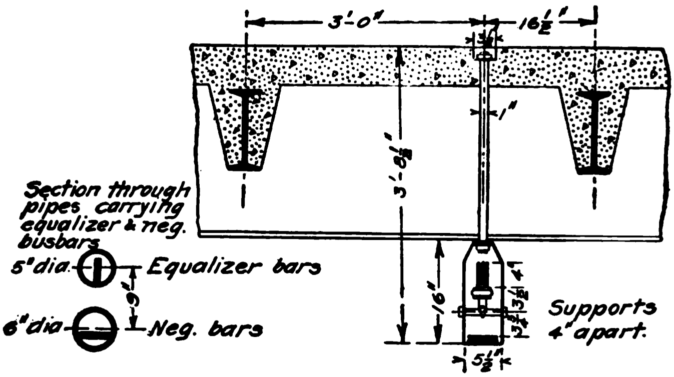


Fig. 50.—Method of Supporting Negative and Equalizer Busbars Between Engine Foundations.

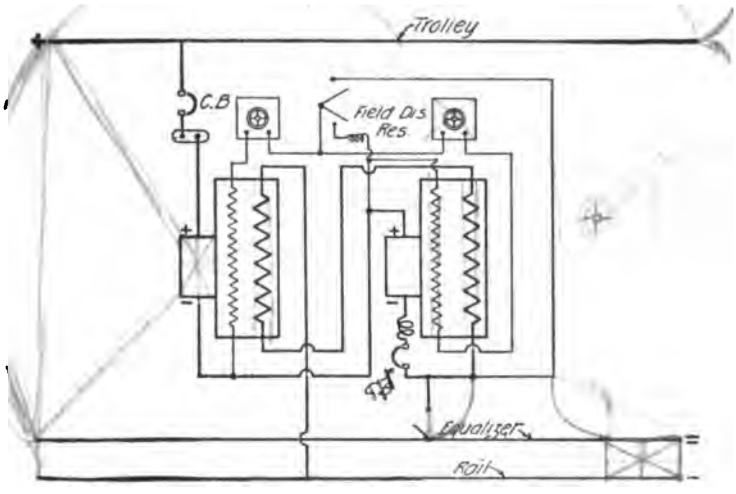


Fig. 51.—Indianapolis and Louisville 1200-Volt Railway: Method of Connection of Two 600-Volt Generators.

LIGHTING SWITCHBOARD

Figs. 52 and 53 show a combined system where an independent generator delivers a 600-volt direct current, and an independent three-wire system is used for lighting purposes.

The d.c. generator of 300 kw. rating and 575 volts furnishes energy for two sets of feeders. Both busbars are mounted on the board, which therefore requires two single-pole lever switches on each board. The generator is a part of a motor-generator set and is to be arranged for d.c. starting. A four-throw starting switch should be mounted on the generator panel. The three-wire system is fed by two low-tension generators connected in series (Chapter VI, case 1), and by a synchronous converter (Chapter VI, case 4). Both generators are coupled to an a.c. motor (induction or synchronous), and are started on the d.c. side. If they are driven by

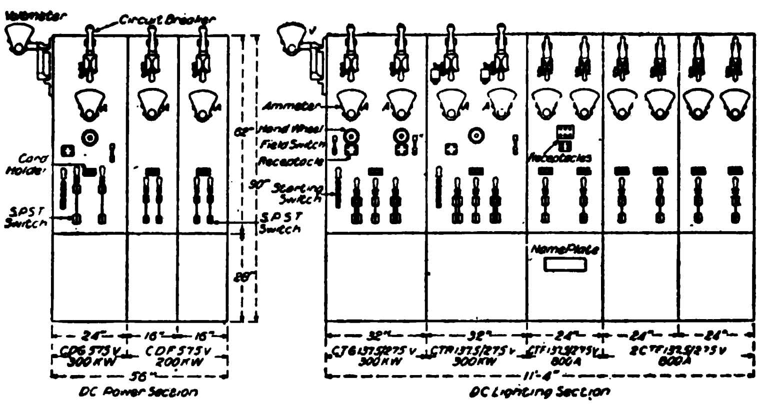


FIG. 52.—Front View of Direct-Current Switchboard.

an engine the starting switch can be omitted. The equipment for both generators is mounted on one panel. The converter, as well as the generators, is shunt-wound since it is thus better suited for lighting purposes. Circuit breakers with shunt coil and ammeters are inserted on both positive and negative sides of the converter. The diagram indicates that the converter is started on the d.c. side. Note that the shunt field windings of both generators are in multiple with the side which the respective generator supplies. The feeders can be connected to the positive and negative bus, or to either of these and the neutral. Both mains of a feeder set are supplied with a circuit breaker and an ammeter. The voltage between any two buses can be ascertained by using an eight-point receptacle and a voltmeter.

The design of the panels for a low-tension feeder system for lighting purposes in large cities, as New York and Chicago, obviously requires particular care. One of the main objects in such a design is to control safely and conveniently a maxi-

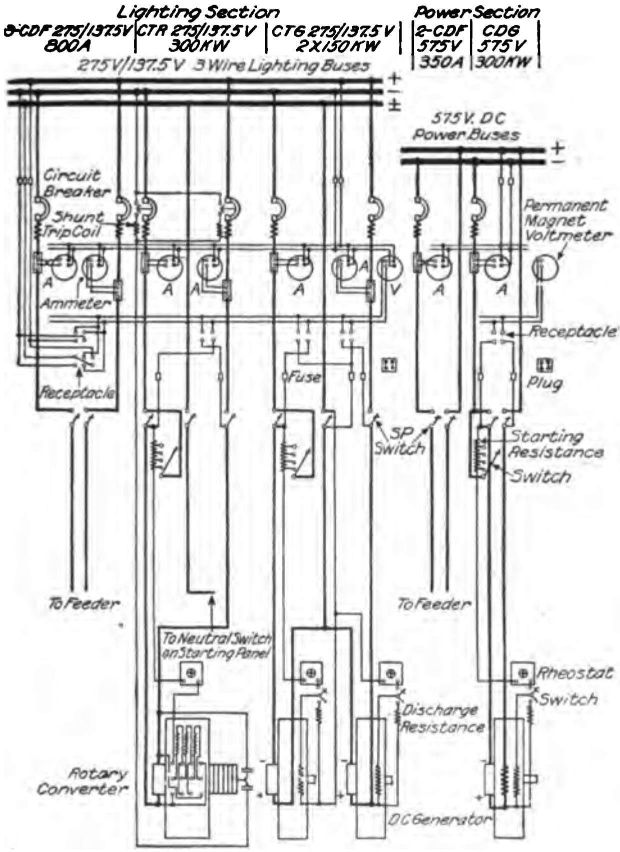


FIG. 53.—Wiring Diagram of Board Shown in Fig. 52.

mum number of feeders from a minimum number of panels.* Fig. 54 shows front, rear, and side views of the feeder panels used by the Chicago Edison Company, in their sub-station for feeding the three-wire lighting system. The board controls four

* Edward Schildhauer, "Recent Design in D.C. Switchboards," *Electrical World*, December 1, 1906.

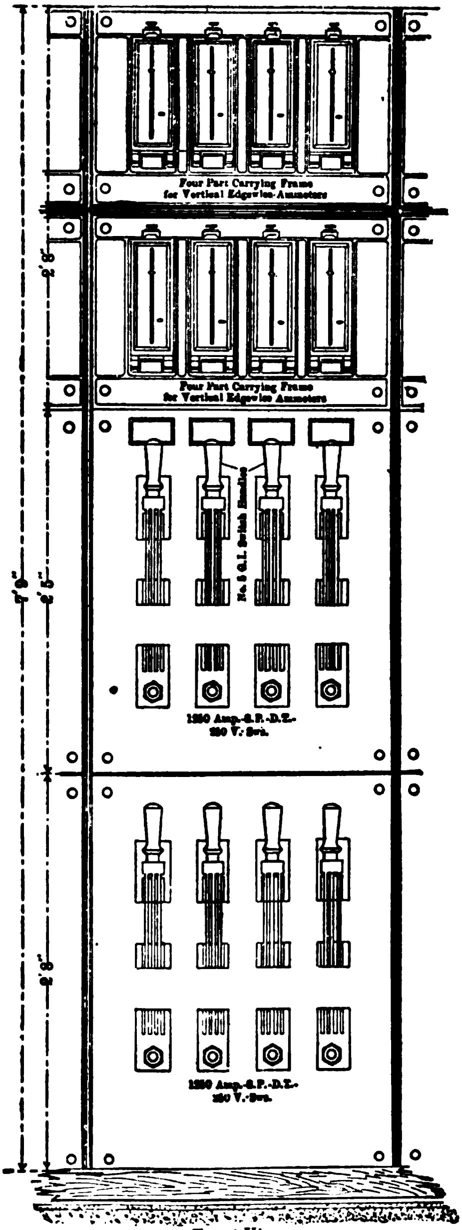


Fig. 54a.—Front View of 1250-Ampere Feeder Panel (Chicago Edison Co.).

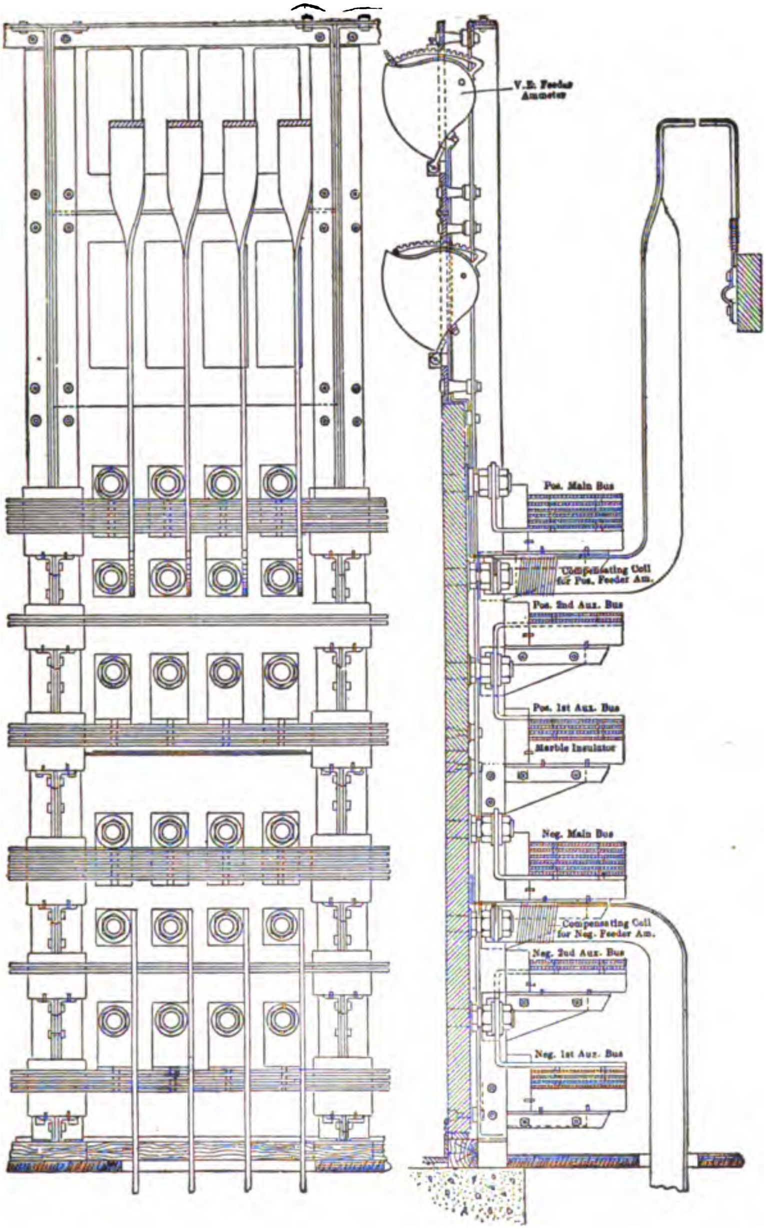


FIG. 54b.—Rear Elevation and Cross Section of 1250-Ampere Feeder Panel (Chicago Edison Co.).

sets of feeders, which can be connected to the main or to either of the auxiliary buses by means of double-throw switches. All

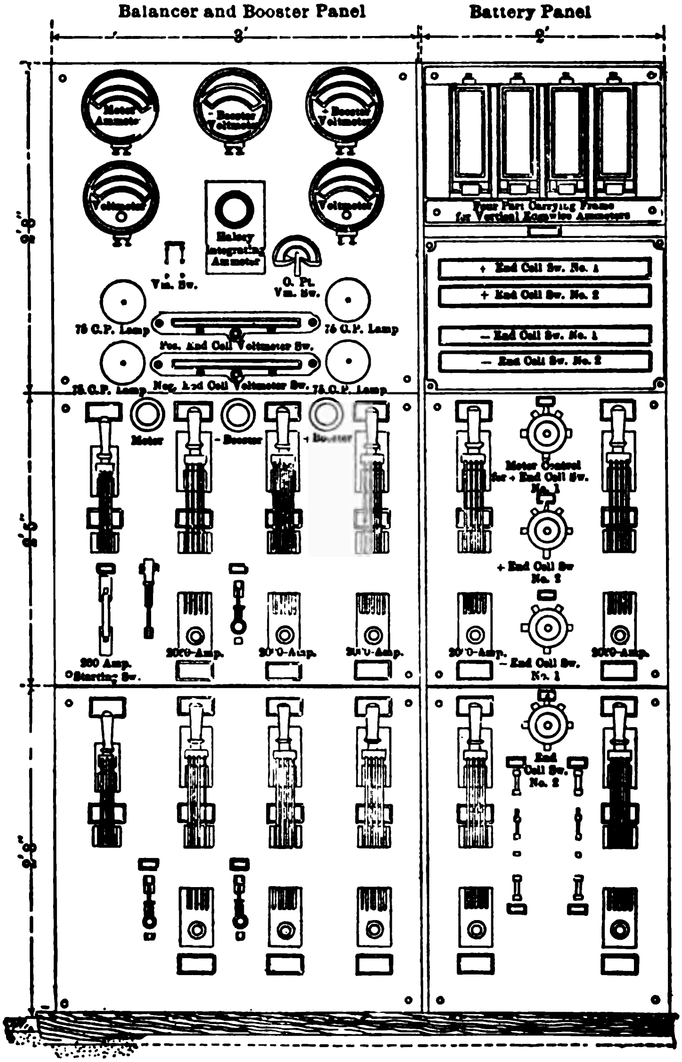


Fig. 55a.—Front Elevation of Battery, Balancer, and Booster Panels (Chicago Edison Co.).

buses are mounted horizontally. This insures the best separation of potential, and, at the same time, the greatest accessibil-

ity to the rear of the switchboard. The connections between studs and buses are made by simple pieces of bent copper,

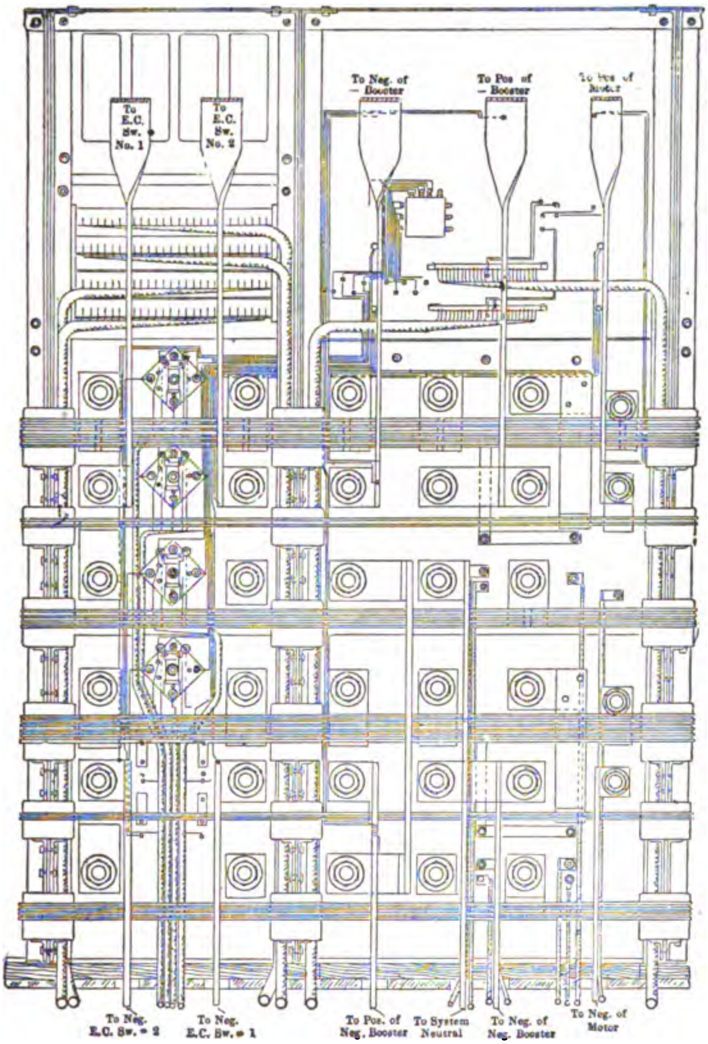


Fig. 55*b*.—Rear Elevation of Battery, Balancer, and Booster Panels (Chicago Edison Co.).

which facilitate the interchange of connections. The horizontal mounting of the buses has the further advantage of mak-

ing it easy to increase the cross section of the buses by addition of copper bars. The poorer ventilation due to this mounting is partly compensated for by a liberal allowance of copper in the bars. Such allowance has the advantage of eliminating to a certain degree the unsafe handling of live buses when an addition of bars is required. The middle studs of the positive double-throw switches are connected to the fuses on the opposite rear wall through bent pieces of copper. The positive feeders lead from the lower terminals of the fuses to the outgoing tile ducts. The cost of the copper bends is more than compensated for by the elimination of the cable racks and the gain in walking space between panels and wall. Two ammeters are supplied for each feeder set. The bar connections between the center studs of the switches and the fuses can be used as ammeter shunt by applying a compensating coil for temperature correction. The connections for the center studs of the negative switches run down below the floor line, and up to the negative fuses on the same back wall mentioned above. The floor is made of 1 in. removable slate slabs protecting the negative connections. The neutrals of the feeders terminate at the neutral bus located in the basement. Fig. 55 shows front and rear elevations of battery, balancer, and booster panels, using the same method of busbar mounting. It will be seen that the studs, nuts, and bolts are as accessible in these as in the feeder panels.

PART II

ALTERNATING CURRENT

CHAPTER XII

LOW-TENSION ALTERNATING CURRENT

Alternating currents cover a much more varied field of application than do direct currents, since they are employed in practice in different forms and quantities of phase, frequency, e.m.f., and power, and since direct current may be regarded as no more than rectified alternating current. Their treatment from the moment of generation through the successive steps to consumption is therefore subject to much greater variation in regard to the four cardinal points established in Chapter I, than is that of the direct current. The electrical equipment of a.c. plants depends mostly upon the output voltage and kw. rating of the units. Alternating current systems may be classified with respect to voltage, as follows:

1. Systems of the same e.m.f. as those employing direct current, 240 to 600 volts (110 volts).
2. Systems whose e.m.f. ranges from 600 volts to 33,000 volts, which are those most commonly used.
3. Systems of extra high e.m.f., ranging from 33,000 to 100,000 volts, used for the most recently designed long distance transmission systems.

We will first treat classification No. 1, since it differs entirely from the other two. Classes 2 and 3 have many points in common, and will be treated together, emphasizing only those differences due to extra high voltages.

GENERATOR (240-600 VOLTS)

Alternating-current generators are used for small industrial plants or mining purposes. They supply three-phase current and are rated at from 20 to 400 kw. Fig. 56 shows a wiring diagram and front and side elevations of a switchboard for a 240-volt generator of this type. A separate exciter mounted on the shaft delivers direct current for the field of the generator.

With larger units the exciter is driven independently, and, as we shall see later on, constitutes a very important part of the central station. A separate rheostat regulates the shunt field winding. The value of the current supplied to the field circuit of the alternator is regulated by a second rheostat, and is indicated by a field ammeter. A double-pole field-discharge switch closes the field circuit. This is provided with carbon break and discharge switches for connection to the discharge

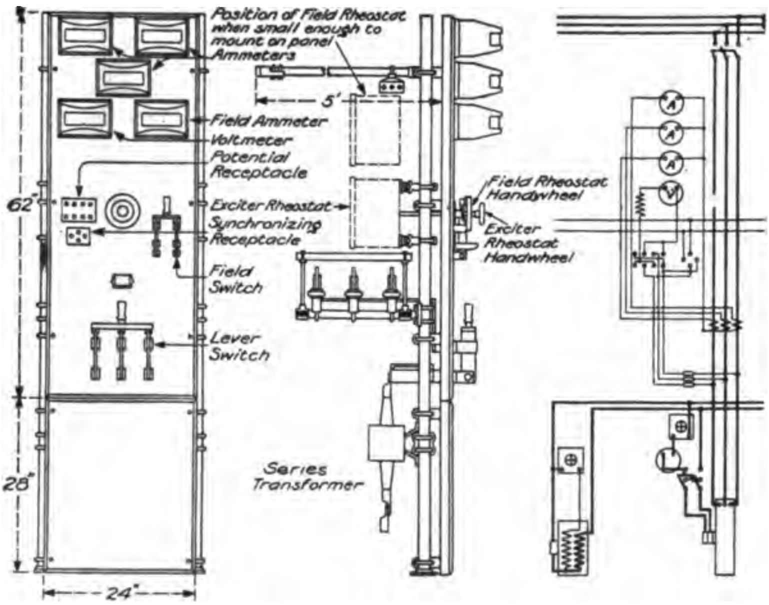


FIG. 56.—240-Volt Three-Phase Generator Panel.

resistance. With the low tension used, the connection of the generator cables with the buses is easily accomplished through a three-pole lever switch. The value of the current of each phase is indicated by separate ammeters, which are connected directly to the line for currents below 300 amp.; above this point series transformers are used. A voltmeter, receptacles, and corresponding plugs are used to indicate the voltage across any two phases. By this means the voltage between any phase and the neutral of the machine can be indicated in case the neutral of the generator is used for lighting purposes at 125

volts. In this case the load is unbalanced. Before an alternator can be thrown into parallel with other machines in service it must be synchronized with them. Synchronism indicators and lamps in connection with receptacles and plugs serve to indicate the difference in phase of the machine in starting. The side elevation shows how the three busbars are mounted. They are protected from foreign objects which might cause short-circuiting, such as tools, by means of a

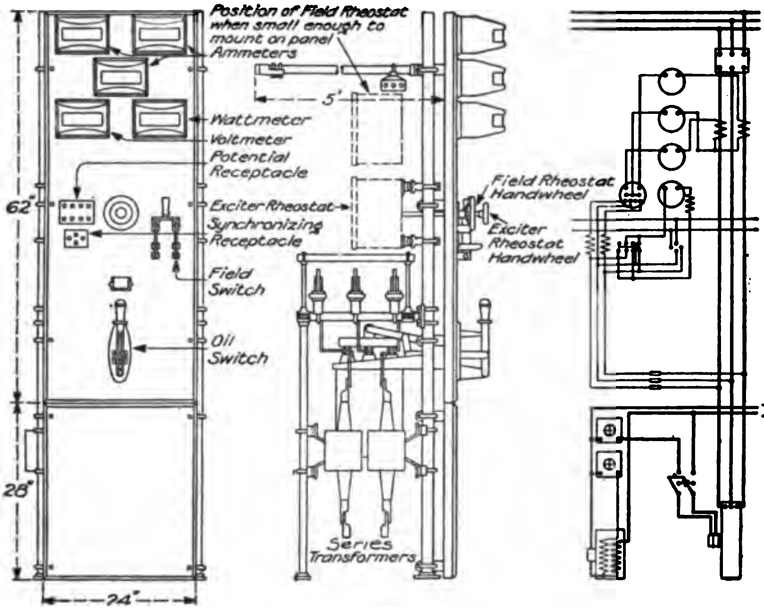


FIG. 57.—480 and 600-Volt Three-Phase Generator Panel.

screen. If the buses are very heavy because of larger output of the generators, the supporting arm is stayed by a gaspipe running up from the floor. The board is mounted and fastened to the rear wall with angles, tees, or gaspipes. These supports also carry the series transformers and rheostats. The rheostats are operated by handwheels directly from the front of the board. If the alternator delivers a higher voltage the connection to the buses is made through an oil switch. This is shown in Fig. 57, for a 480- to 600-volt machine. Instead of using an ammeter to indicate the necessary amount of field regulation, the voltmeter or synchroscope may be em-

ployed to perform this function. For balanced loads and current under 50 amp. one ammeter in the middle leg suffices. For larger current values the ammeter must be connected to two series transformers in the outside legs. For unbalanced load the arrangement is the same as that described for Fig. 56. A polyphase wattmeter indicates the total output of the machine, and by comparison of the ammeter and wattmeter indications the power-factor of the circuit can be determined. The oil switch interrupts the current under oil in order to eliminate

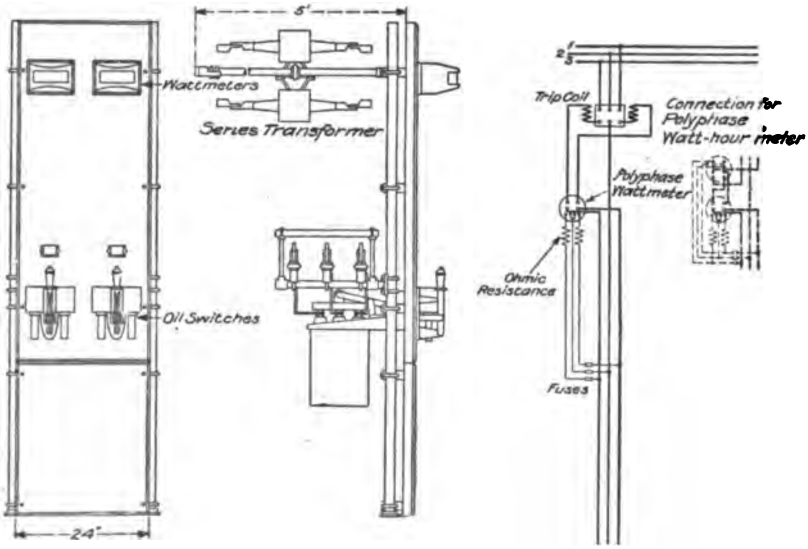


FIG. 58.—480 and 600-Volt Two-Circuit Feeder Panel with Oil Switches.

the danger due to the arc between the contacts of the switch at the moment of interruption. It is mounted on the rear of the board and is operated by a handle from the front. (See Chapter XVI.) All voltage-carrying instruments are protected with fuses against overload. One synchroscope may be used for several generators, in which case it is mounted on a swinging bracket on the generator side of the board.

A.C. FEEDERS

The energy is drawn from the three busbars through an oil switch or circuit breaker. Both of these pieces of apparatus

are equipped with tripping coils which operate to interrupt the circuit at overload. Figs. 58 and 59 show the wiring diagram and switchboard for a.c. feeders. As we wish to ascertain the amount of power consumption of each feeder system a polyphase wattmeter must be connected into the line. A special polyphase watt-hour meter with series transformer may be used to measure the energy output. The feeders are gener-

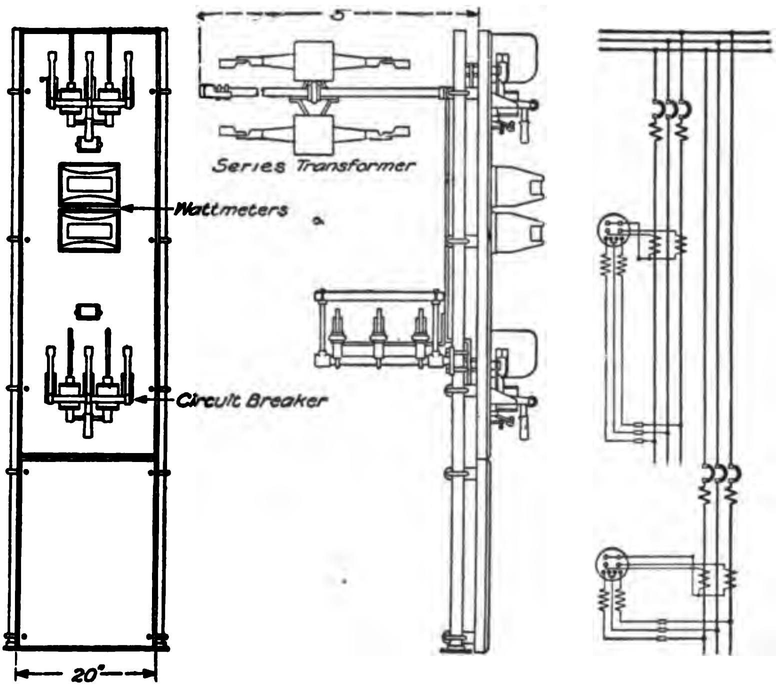


FIG. 59.—240, 480 and 600-Volt Two-Circuit Feeder Panels with Circuit.

ally run from the buses and oil switches or circuit breakers to the nearest wall, whence they lead to the place of consumption in the factory. The series transformers are therefore mounted on pipes near the top of the board. This differs from the method of mounting for generator panels where we saw that the apparatus was mounted near the base of the board. This was due to the fact that the three feeders from the generator reached the board from below.

Alternating low-tension switchboards are identical with

d.c. boards in respect to material of board, method of setting up, copper connections, spacing between busbars, and mounting of same, as illustrated in the accompanying figures. Up to this point we have had to deal with voltages requiring no special safety devices, with the possible exception of circuits requiring interruption in oil on account of induction phenomena.

CHAPTER XIII

HIGH-TENSION SWITCHING ARRANGEMENT AND METHODS OF CONNECTION

In order to make a correct choice of the various switching arrangements for a plant, an investigation of the following points is essential: 1. Cost. 2. Reliability and continuity of the service. 3. Greatest protection of life and property. 4. Available space. 5. Voltage and capacity of plant.

The order of investigation of the above-mentioned points will depend upon the case in hand. It may be a question whether more consideration is due to the stockholders or to the public, or if the system is one for extended electric traction service or only street railway service, etc.

1. In regard to cost it must be kept in mind that improvements, safety appliances, continuity of service, and future extension, will involve not only the first cost, but additional expense for maintenance, repair, and operation. After taking all these matters into consideration, our final estimate must show that a reasonable return on the investment may be expected.

2. The reliability and continuity of the service are in fact the main objects of the plant. If these conditions of stability do not exist, and if frequent prolonged interruptions of service occur, the consumers will suffer, and the public become prejudiced. Such conditions will give material advantage to competitors, and may eventually lead to forfeiture of franchises or other concessions. These important considerations together with those discussed above afford the engineer a clue as to what methods to adopt in order to insure the desired conditions of reliability, continuity, and adaptability of service. The amount of useful information thus obtainable depends upon the conditions which show to what extent our object may be accomplished by the best machines and material in the market, by installation of greater or less number of auxiliary ap-

paratus with their connections, or by establishing a reserve of units and parts. It should be noted that the greater the adaptability, the greater is the amount of apparaus necessary, and hence, the greater the liability for disturbances.

3. Since legal requirements as to protection of life and property must be complied with, devices guarding against lightning and fire, special arrangement of apparatus, and the use of special insulating material become important factors in the plant.

4. Here we have two cases to consider. In the first case the building site need not be bought. As an example, an old d.c. station may be converted into a modern a.c. plant on the same site, or an addition to the old station may be built on land already owned. In the second case the site must be bought, and we here again have two distinctions to make. The choice of building sites is either determined by the location of a given source of water power with respect to the central station or by the location of load centers with respect to sub-stations, or the choice is limited only to certain minor considerations, thus allowing greater freedom of selection. (See a.c. plants.)

5. The power rating of a plant depends, on the one hand, upon the object of the plant, which includes quantity and character of the output, and on the other hand, upon the available mechanical energy. The voltage of the generators to be selected increases with the size of the machines, for instance, 2300 volts up to a power rating of 2000 kw., and 6600 volts for higher ratings. Machines of 5000 kw. rating may have a voltage of 11,000 10-cycle, or 13,200 25-cycle. An e.m.f. of 22,000 volts is admissible with certain powers, speeds, and frequencies. For long-distance transmission lines where the copper weight of the line adds materially to the cost of the system, the voltages of the generators are stepped up, giving up e.m.fs. of 11,000, 15,000, 22,000, 33,000, 44,000, 66,000, 88,000, and 100,000 volts. The most usual frequencies employed are 25 and 60 cycles, the former for traction and motor-power distribution, and the latter for lighting. Units supplying energy to motors should be so chosen that their maximum overload capacity is of such value that in case one of the units is momentarily thrown out of service, the output of the station and the voltage are not materially

affected. It is therefore desirable to have one reserve unit, to be used only in case of emergency or at overload, thus making it possible to repair disabled machines, The determination of the capacity of the individual units is a very important matter. For although the cost per kilowatt varies inversely, the capital invested for the reserve varies directly as the power rating of the machine. If the number of the machines is large the ratio of reserve cost to total cost is small, and is partly compensated for by the greater adaptability of the service and the decrease in line loss which the reserve accomplishes. The relation of the area included between the load curve and the time axes, to the area under the rated output curve of the machine, is called the load factor of the plant. A high degree of efficiency, if obtained for a long period of time, re-

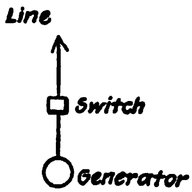


Fig. 60.—Simple Single-Unit System.

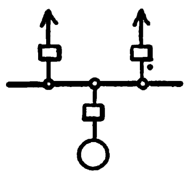


Fig. 61.—One Bus System.

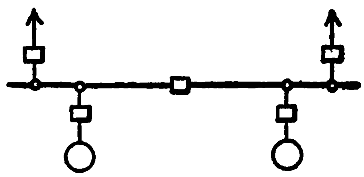


Fig. 62.—One Bus with Sectionalizing Switch.

quires the use of larger power units, which again decreases the overload limit of the machines. If the load curve is flat, a smaller reserve unit may be used to take up the overload. If water power or steam turbines are used, all machines, including the reserve, may be run at all times on low load, since in this case no material losses in water or steam power need be considered. This method of operation differs from that employed with steam engines, which run economically only at full load, and require the use of the reserve only from time to time.

In the diagrams herewith the cable connections between machines and pieces of apparatus are represented by single lines. They therefore show the arrangements without regard to phases of the machines. The simplest case is that in which the generator feeds directly into the line (see Fig. 60), which is connected to the machine through an oil switch. If a ma-

chine is to supply several feeders, the energy is first led to busbars, whence the necessary amount for individual feeders is drawn off through oil switches. (See Fig. 61.)

If two or more generators are used to supply the feeders the switching arrangement becomes more flexible by inserting a bus-sectionalizing switch in the busbars between generator connections. This switch enables the attendant to feed any set of feeders from any machine. By its use a disturbance on one side of it is localized and cannot affect the generators or connections on the other side. (See Fig. 62.) In another system, each generator feeds one line directly, as shown in Fig. 60, but the feeders are connected by an auxiliary bus, so that, in case of need, one feeder can be supplied from the other genera-

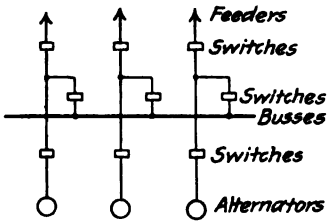


Fig. 63.—Relay System.

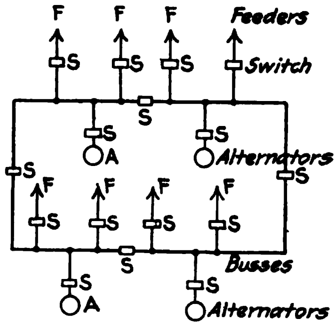


Fig. 64.—Ring System.

tors. This is the relay system. (See Fig. 63.) Fig. 64 shows a ring system where sectionalizing switches are inserted in the buses between each group of feeders and their corresponding generator. The advantage of this system is that any disturbance can be confined to a small part of the station, if a greater number of generators and feeders are required to maintain the service. The best and most common method of switching arrangement is that where a double set of busbars are employed, one called main or operating bus, and the other auxiliary bus. (See Fig. 65.) This method is more expensive because it requires two oil switches for each feeder and generator, and an additional weight in copper for busbars and connections. On the other hand, it affords an easy means of feeding any group of feeders from any group of generators.

Such an arrangement has the further advantage that repairs of any part of the busbars can be made without danger and without interrupting the main service, since such part is easily disconnected from the live parts. This system is used when a considerable number of feeders are in service all day, or when it is desired to keep separate two different kinds of load.

For street railway systems in large cities where the central and sub-stations are connected through a large number of feeders, a system called the group system is employed. (Fig. 66.) The essential point of this system is the grouping of the feeders which are connected to auxiliary buses. These buses

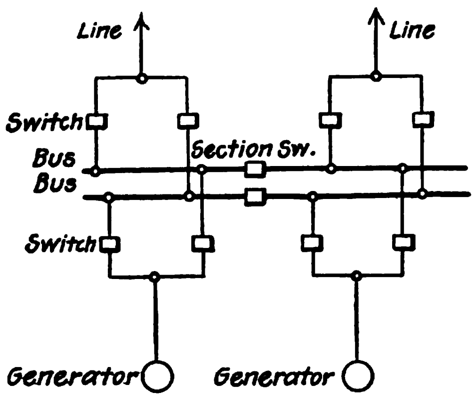


Fig. 65.—Duplicate Set of Bus Bars.

are supplied from the main buses, which are in turn fed by the generators. Systems of this kind are used in the plants of the New York Street Railway Co., at 96th Street, and at Kingsbridge, in the 74th Street Station of the Manhattan R. R. Co., and also in the power house of the Long Island R. R. Co., to be described later. The advantages of such a system are as follows:* (a) "It affords an additional means of opening a feeder switch that fails to open its circuit when operated for that purpose." This applied mostly to oil switches in their early days when two switches in series were required to insure

* L. B. Stillwell, "The Use of Group Switches in Large Power Plants," March 25, 1904, Proceedings, A. I. E. E.

their proper operation. This consideration is no longer of importance, on account of the advance made in the construction of these switches. "They act as an assurance against a shutdown in a more important service." (b) "It affords means of reducing aggregate load upon the power house, in case of necessity, more rapidly and is otherwise less objectionable than the usual method of cutting off individual feeders. It will sometimes happen in the operation of a power plant that it becomes necessary suddenly to shut down one of the generating units. If the load carried at the time be such that the shutting down

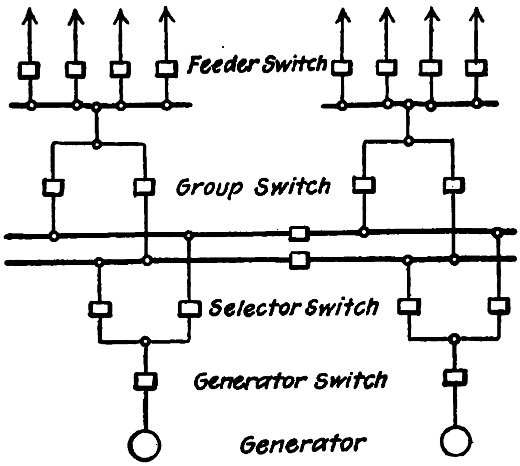


FIG. 66.—Group System.

of the generator implies reduction of the external load, this can be accomplished most conveniently by operating one or two group switches." An objection to this point is that a group of feeders can also be simultaneously disconnected in other cheaper ways. The oil switches for a group of feeders can be electrically or mechanically interlocked in such a way that by the operation of a control switch all the feeder switches of a group can be opened simultaneously, while the several circuits still retain their individual control. (c) "Where duplicate main busbars are used it facilitates transfer of load from one set to the other, in case it becomes necessary suddenly in operation to make such transfer. If the feeders were connected

to two main buses, it would become necessary to supply two oil switches apiece, or 2, 3, or 4-pole double-throw switches for low tension. In the present case, however, there suffice one switch per feeder, and two oil switches per feeder group, which cuts down the number of switches necessary to be operated for transfer." (d) "The grouping of the external feeder circuits in group units being a simple fixed relation to the generator units, establishes a symmetry and proportion most useful to the operator, particularly in time of emergency. The portion of load per group of feeders is known from the number and size of the feeder groups in relation to the number and size of the generators. With partial load it is easy to determine if a generator may be cut out of service, thus throwing its load on to other machines, or if it is better to disconnect a whole group of feeders, thus throwing the load of the sub-stations onto the other feeders." The above applies to city service, where several independent feeders lead to each sub-station.

Arguments against the group switch are: (a) "It introduces additional apparatus, and therefore in itself increases the risk of interruption due to failure in switch insulation, etc., and of disturbances which may often be more harmful than those which the switches are supposed to prevent." (b) "It implies an increase in cost of the plant. In the case of the Manhattan plant this increase is about 10 per cent. of the cost of the switchgear and measuring apparatus and about 0.4 per cent. of the cost of the plant. So that in a large plant the cost is negligible in comparison to the gain."

Generally no definite rules can be formulated as to when and where such a system is of advantage. A choice of systems depends upon the conditions of the case in hand.

Fig. 67 shows connections for alternator, transformer bank, switch, and line. It represents the case where a number of plants feed into the same system.

A layout for several feeders in connection with one transformer bank and one generator is given in Fig. 68. An oil switch is inserted on the high tension side of the transformer. In Fig. 69 two sets of busbars are used, one for the low tension, and one for the high-tension side of the transformers. The first set is fed by the generators, and the second is connected to the feeders. Both sides of the transformer are pro-

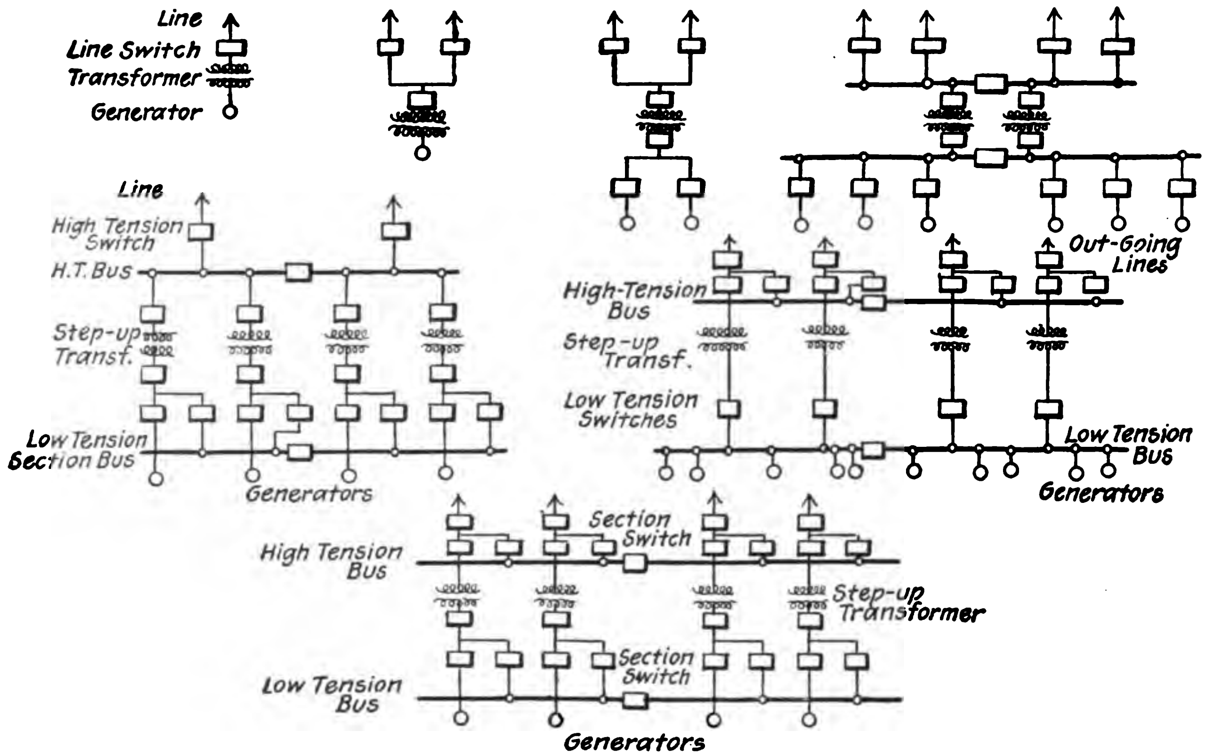


FIG. 67 —Single-Unit System. FIG. 68.—Single Generator-Transform Unit Multiple Feeders. FIG. 69.—Single Transform with Multiple Generators and Feeders. FIG. 70.—Units Like the One in Fig. 69, Connected Together with Sectionalizing Switches. FIG. 71.—Generator-Transformer Unit System. FIG. 72—Transformer-Line Unit System. FIG. 73.—Generator-Transformer-Line Unit System.

tected by oil switches. In Fig. 70 we have two or more transformer banks and a large number of generators and feeders, and desire to make their operation independent. This is accomplished by insertion of sectionizing switches in both high and low-tension buses, between the transformer connections. We are thus enabled to divide all units into groups with corresponding transformers and feeders. The arrangement corresponds more or less to that of Fig. 62.

One of the most modern switching arrangements is represented in Fig. 71. Each transformer bank is directly connected with its generator and with the low-tension busbar. By running in parallel on the low-tension side only, any generator can be run with any transformer. The whole station can be run in parallel or two parts run separately. This represents a case where the generator power is sufficiently large to allow of a generator-transformer-unit combination with the duplicate outgoing line. If, however, the generators are of smaller power, and we wish to form a transformer-line unit, the arrangement of Fig. 72 is used. The feeder is directly connected with its transformer, and also has a connection to the high-tension busbar. The connection of any feeder with any transformer is thus made possible.

Fig. 73 is a combination of Figs. 71 and 72. The unit is made up of generator, transformer, and line. Each unit can be operated independently as shown in Fig. 66, or any desired combination may be employed.

The systems described above are only typical arrangements, and may be modified by using varied combinations of different systems or by addition of auxiliary buses or other apparatus. As already stated the arrangement is subject to no fixed rules, but to the judgment of the engineer.

CHAPTER XIV

CIRCUIT INTERRUPTING DEVICES

In this chapter we shall discuss the principles involved in the application of instruments and apparatus of standard make.

One of the most important parts of a high-tension system is the circuit interrupting device. Its functions are the same as those of a d.c. circuit breaker, i.e., to open or close the circuit at certain critical moments. Such instants may be foreseen or they may occur suddenly, necessitating instantaneous operation of the apparatus. In the first case, the breakers are operated manually, and in the second case, automatically. The automatic type can also be operated manually. With medium voltages, where on account of insulation, the size of the apparatus does not become excessive, such apparatus may be mounted on the board, or in its vicinity on supporting frames or in cells. With high and extra high tension more space must be allowed for the apparatus on account of the high insulation. They are therefore located away from the board. In the former case they are operated mechanically from the board, and in the latter instance their operation is either manual, electric, or pneumatic. Four groups of circuit breaking devices may be differentiated according to their make, operation, voltage, and the load to which they are connected. These are:

1. Disconnecting switches.
2. Plug switches.
3. Fuses.
4. Circuit breakers and oil switches.

The general conditions for which these breakers must be designed are as follows:

1. The rated current of the device ought to be carried with negligible drop and no heating. This depends upon the material of which the switch is constructed, upon its dimensions,

and upon the construction and pressure between the surfaces of the contact pieces.

2. To insulate all live parts for maximum potential, both in an electrically and mechanically permanent manner. The best criterion for the judgment of the efficiency of a circuit breaker, is the extent of its ability to maintain perfect insulation in spite of the formation of arcs. The higher the voltage the more difficult does it become to obtain perfect insulation in service. Every breaker is therefore rated for a maximum voltage.

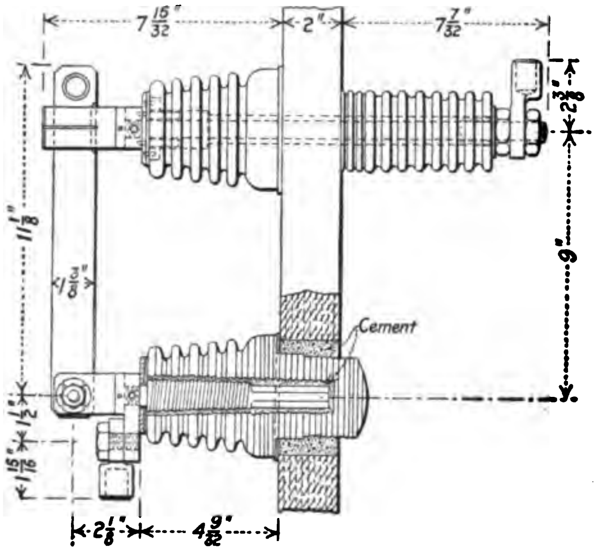


FIG. 74.—12,000-Volt Disconnecting Switch.

3. Mechanical means have to be provided for opening the circuit, which may be either automatic, or non-automatic as stated above. Fuses are always automatic, disconnecting switches and plug switches non-automatic, and oil switches and circuit breakers may be either automatic or non-automatic.

4. The formation of arcs has to be prevented or rendered harmless. This requirement may be met in various ways. The contacts may be widely separated, the interruption may be made to take place in oil, the arc may be blown out magnetically, or through air expulsion or may be quenched in an inclosure. Choice of the above-mentioned methods depends

upon the voltage, space, conditions of service, etc., as we shall see under the discussions of the various types of breakers.

The d.c. circuit breakers and the a.c. breakers up to 600 volts were treated in Chapter IX.

DISCONNECTING SWITCHES

This type of breaker is seldom used by itself for main current interruption, being usually used in conjunction with an oil

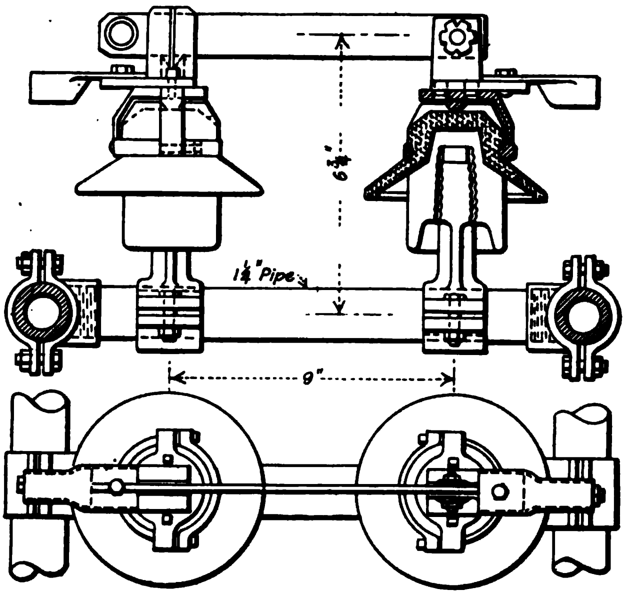


FIG. 75.—16,000-Volt Disconnecting Switch on Line Insulators.

switch. If the breaker is to be used independently to break the line current, it has one great disadvantage. In order to break the arc the contact studs must be placed far apart, thus consuming a great deal of space for installation and operation. It can be used only when the voltage drops to a low value, for otherwise the arc would produce a high potential oscillation in circuits of high inductance and capacity. These potential oscillations are quite liable to destroy the insulation at some part of the circuit, especially in the transformers. When used in conjunction with an oil switch it serves to disconnect the

terminals of the latter from the live parts of the line, the oil switch having previously been opened. It is used to connect lightning arresters or potential transformers to the main line. Fig. 74 shows a 12,000-volt, 300-amp., disconnecting switch mounted on a slate base. One of the terminals is in front, and the other on the back side of the base, or the positions of the terminals may be varied according to circumstances. The hinge studs are incased in porcelain or glass bushings, with the surface distance between metal parts and base corresponding to the voltage, usually being taken at 1 in. per 1000 volts. The air space between metal parts, and between these and

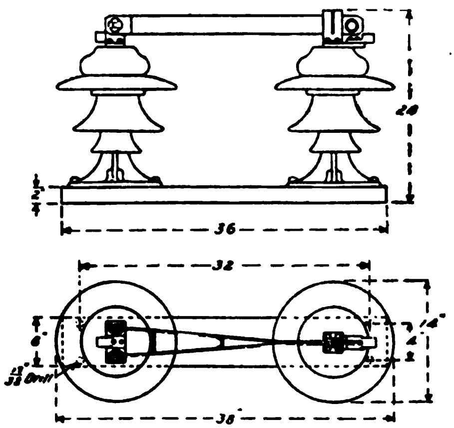


FIG. 76.—60,000-Volt Disconnecting Switch on Line Insulators.

ground, and the dimensions of the metal parts are dependent upon the voltage and capacity of the line. The air line distance equals half the surface distance. Another method of mounting disconnecting switches is shown in Fig. 75. The porcelain insulators are fixed on a pipe support. A metal cap is fastened on the top of the insulators on which are mounted the clips of the disconnecting switch. The terminals can be located in the front only. The illustration shows a 16,000-volt, 300 to 800-amp. switch. The support may be slate instead of piping, as shown in Fig. 76 for a 40,000 to 60,000-volt switch.

All these switches are mounted out of reach, so that operators cannot accidentally come into contact with live parts. It is advisable to separate the switches of different

phase by slate, marble, or asbestos barriers in order to protect them against arcing, or a short-circuit across the phases. The barriers become superfluous when there is sufficient room for a safe separation of the switches. All disconnecting switches are operated with a hooked pole. The attendant must therefore have sufficient room in which to use the pole, which is from 2 to 3 feet for low tension, and 10 feet for voltages up to 60,000. The cable connection should be such that, when the switch is open, the handle will be dead.

Another type of disconnecting device is the bus-sectionalizing switch. The busbar is broken for 6-in., and both ends are in

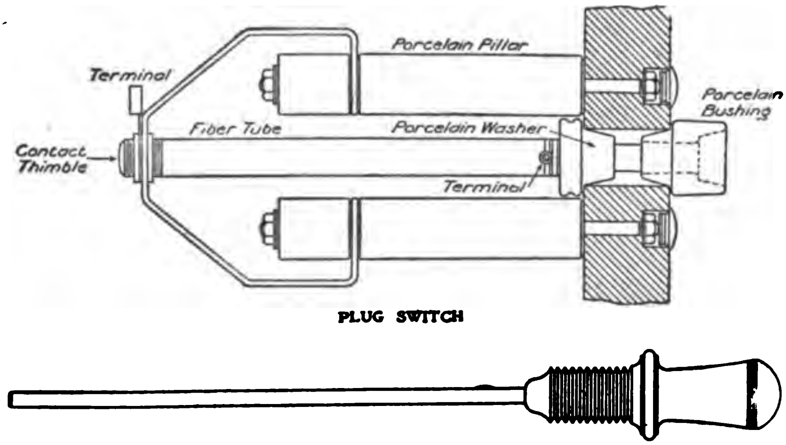


Fig. 77.—Primary Plug Switch.

the form of clips. A copper link with an eye connects the two parts. Still another type of breaker for open air use resembles the horn type of lightning arrester. The main part is built exactly like one of these arresters, the air gap being bridged by a terminal part which, when the switch is actuated, is drawn away. The arc then breaks itself by drawing towards the upper ends of the horns, where they are farther apart than at the base. The current of a 1500-kw. generator, at 26,000 volts, has been ruptured in this way. If the disconnecting switch is to be mounted overhead horizontally for high tensions, the handle is fastened to the pins of the insulators, and the tops of the insulators are fastened to the base by means of a cap.

PLUG SWITCHES

A plug switch consists of one fixed and one movable part. The fixed part carries the contacts between which connection is to be made. The movable part is a metal plug with insulated handle which connects the contacts when inserted in a porcelain bushing. The plug switch with plug is shown in Fig. 77. The switch is from 5000 to 10,000 volts, 10 amp. One of the

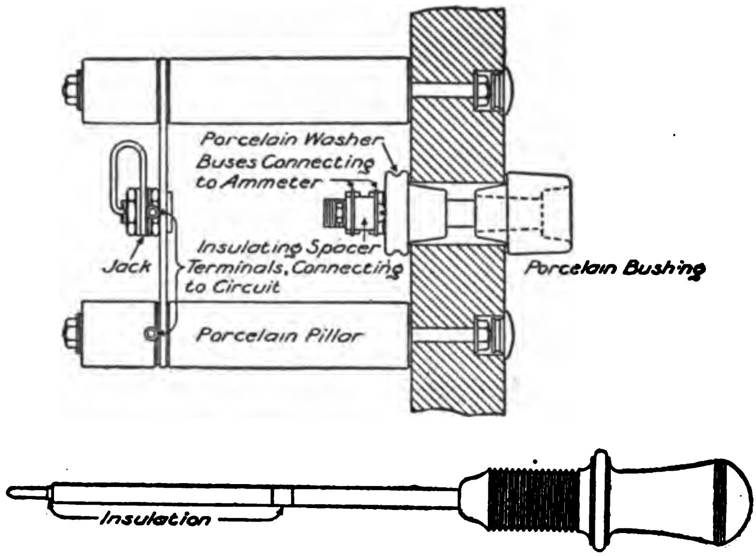


FIG. 78.—Ammeter Jack.

contact terminals is mounted on a fiber tube on the end near the switchboard, and the other on the farther end of the tube. The tube forms a receptacle for the plug. The bushing on the front of the panel prevents accidental touching of live parts of the switch, and at the same time serves as insulator for the fixed part and the board, as do also the porcelain pillars on the back of the board.

Another type is shown in Fig. 78. Two copper buses insulated from each other are mounted on the fixed part back of the board. Two terminal contacts are provided on the farther side. As long as the plug is inserted in the receptacle, it

separates the two cable contacts, but connects them at the same time with their respective buses near the board. When the plug is removed the contacts are connected together. The buses are permanently connected with the series transformer of the ammeter. The contact terminals are on the side of the main circuit, and, as mentioned above, are connected when the plug is out. Plug switches are used for series alternating systems of arc or incandescent lighting in conjunction with constant-current transformers. (See Chapter XIX.) They close the circuit on the primary side of the transformer, which generally carries from 1150 to 2300 volts, and which is protected by fuses against overload. The secondary side of the transformer is generally measured by the number of lamps connected to it in series, this number varying between 15 and 100 for different transformers. By means of the plug switches the circuit can be opened, short-circuited, or transferred to other lines. Any arc forming in the fiber tube (Fig. 77) is quickly quenched. On the secondary side of transformers, they are used only up to 10 amp., since with larger current the arc is stronger and harder to extinguish. They are therefore often replaced by oil switches.

Fig. 79 shows another method of connecting the ammeter to the circuit. Two cables in the handle lead to the series transformer of the instrument. The plug makes contact between the cables and the metallic springs connected to the circuit. When the plug is taken out, one of the springs snaps back against the other contact, thus restoring the circuit.

The use of this type of switch where many bare parts are connected to high voltages, requires very careful handling and special fireproof mounting.

As we have seen, plug switches are preferably used to connect the series transformer of one ammeter with different lighting circuits. As long as the plug is not inserted in the receptacle, the primary winding of the series transformer is open. To avoid this the General Electric Company has designated a switch so constructed that the plug connects the primary winding with the various circuits, or short-circuits the winding, according to the depth to which it is inserted in the receptacle.

FUSES

We have noted in Part I—direct current—that all voltage-carrying instruments and apparatus must be protected against overload or short-circuit. The simplest and cheapest of such devices is the fuse. For direct-current use fuses are constructed in open link or in closed types. Their purposes for

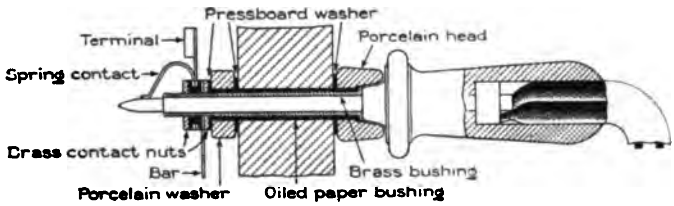


Fig. 79.—Ammeter Jack.

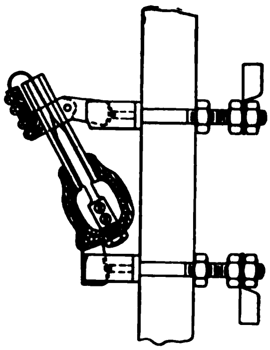


Fig. 80.—Expulsion Fuse.

Fig. 81.—Expulsion Fuse for Shunt Transformer.

alternating current are similar to those for direct current, but their construction differs on account of the high voltages employed. They act automatically and must be replaced by hand before the circuit can be restored. They can be used in series with disconnecting switches, rendering the breaking of the switch at high voltage less troublesome. Fuses are used for very high voltage and amperage. Their construction for high voltage is as follows: (Fig. 80.) The body of the holder consists of an insulated metallic chamber into the upper end of

which is screwed a fiber tube. That part of the fuse in the chamber is of smaller cross section than the remainder, to in-

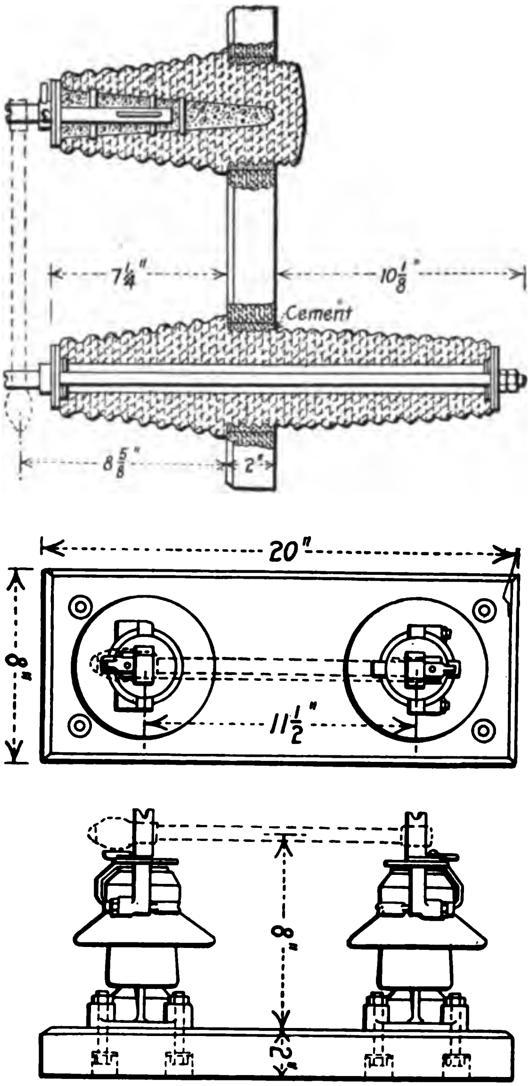


Fig. 82.—Expulsion Fuse for Shunt Transformer as Disconnecting Switches.

sure rupturing at that point. The expansion of the gases formed by the arc in the chamber expels the fused metal and

effectually opens the circuit. The illustration shows the cross section and method of slate or marble mounting of a General Electric Company expulsion fuse for 2300 volts. The lower stud of the holder should be connected to the source of power, and the upper one to the load. All high-tension fuses are fastened on insulated bushings. Fig. 81 shows the cross section of a fuse used for shunt transformers for high voltages. They are often fastened to clips similar to disconnecting switches, and are used to insure safe access to the shunt transformers. (See Fig. 82.) It is recommended that 2300-volt fuse holders be spaced on 12-inch centers, and 6600-volt holders on 18-inch centers, unless barriers are used between them, in which case the centers can be made 5 and 8 inches respectively.

As noted above, fuses can be used only for automatic current interruption with short-circuit or overload in service which permits of their easy replacement. That is, they are useful only when the time required for replacement causes no inconvenience due to interruption of service.

CHAPTER XV

OIL SWITCHES

DEVELOPMENT in oil switch construction has resulted in the production of a number of invaluable pieces of apparatus without which it would be difficult to handle high-tension currents safely and economically. The utilization of oil has made it possible to interrupt circuits of high and extra high tension and power with ease and safety, under most severe conditions of short-circuit or overload, and this without damage to the device itself. The latter point is of great importance, since the breaker must be capable of passing current as soon as the outside disturbance is over. A comparison is made by Mr. E. M. Hewlett of relative merits of oil-break to air-break switches.*

1. "Abnormal rise in pressure—Owing to the fact that in oil switches the circuit is opened at the zero point of the wave, the rise in pressure found in the air-break switch is not experienced. This point is of considerable importance in high-pressure long-distance lines, and in cables carrying considerable energy." The interruption in oil is therefore no quick break action. The effect of the oil as shown by the oscillograph is to make the arc last through several wave lengths, being broken at the zero value.

2. "Power—Experience has proved that oil switches may be designed to break circuits of practically unlimited power."

3. "Length of arc—Owing to the smothering action of the oil on the arc, the length of arc in oil is only a fraction of its length in air."

4. "Insulation—The insulating qualities of the oil decrease the distance required to prevent leakage and arcing."

5. "Size of switch—Owing to the fact that the arc length is materially decreased and the value of the oil as an insulation

* "Oil Switches for High Pressure," by E. M. Hewlet, Proc. A. I. E. E., March 25, 1904.

reduces the creeping surface, an oil switch can be made very much more compact than an air switch."

6. "Remote control—The design of the oil switch lends itself readily to operation by control from a distance."

7. "Arc confined—The fact that the arc is ruptured under the oil within the switch has two advantages; first: switches can be placed close together without danger of short-circuit; second: in case of emergency, confusion is avoided, as there is no visible arc to disconcert the attendant."

8. "Station arrangement—The flexibility of the oil switch places no limitations on the station arrangement, permitting the circuits and buses to be arranged in the most advantageous manner."

9. "Isolation of phases—The possibility of complete isolation of the phases in a reasonable space is easily secured by the use of the oil switch."

Oil switches may be classified according to operation, as automatic and non-automatic. In order that the former may interrupt the circuit at short-circuit or overload they must be self-actuated, and must be able to break a current of several times the generator rating. The non-automatic breakers are not used for such large currents, yet they must be able to interrupt the current when the generator is short-circuited. As to operation we may divide oil switches into three classes:

1. Manually operated.
2. Electrically operated.
3. Pneumatically operated.

1. Manually operated switches of small power rating are mounted on the back of the switchboard, and are operated by means of linkages from the front of the panel. It may sometimes be more convenient or advantageous to mount them on brackets or framework away from the board on the wall or in cells, which may be the case with switches of larger power rating. Under the circumstances they are operated from the board through rods with bell cranks or wire rope.

2. Electrical operation is substituted for manual, when the distance from board to switch and increased size of switch render the above arrangement clumsy or inconvenient. Such manipulation is advantageous under the following conditions:

(a) Oil switches for higher power and voltage are so large

that they can be managed more easily electrically than manually (10,000-kw. stations). If operated mechanically they would occupy too much space.

(b) The switches can be installed in any convenient place independent of the position of the switchboard. A saving in copper may thus be attained by placing them near the source of power and the busbars.

(c) The switches can be located so that they cannot be disturbed through any machine parts like steampipes, etc.

(d) In large stations the attendant is enabled to operate with ease any desired circuit since the oil switches control apparatus are concentrated in a small space on the board.

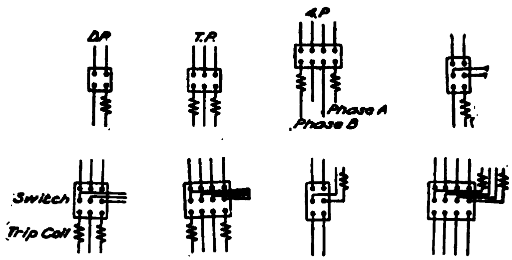


FIG. 83.—Series Trip Coils for K8 Oil Switches (see Fig. 88).

(e) When operating at the switchboard, the attendant is not in danger of coming in contact with high-tension conduits, since only low-tension control wires lead to the board.

(f) Since the attendant is thus assured a safe and isolated place of operation, he is not so easily disconcerted in case of accident when quick action is imperative.

(g) If the switches are inclosed in fireproof cells a fire in any cell can be localized.

In large stations it is important that the control and operation of all generators, exciters, transformers and feeders be concentrated as much as possible, so that one switchboard attendant may control the entire system. This will result in more advantageous management and decrease of operating expenses. In such stations the power units are so large that the distances between machine centers is considerable. Hence, if cables were to be run from these machines to mechanically operated oil switches, a very undesirable position for the switch-

board might be necessitated, if cable cost and ease of installation are taken as criterions. The great danger incurred in handling high-tension apparatus compels us to mount them in such a way that no high-tension wires lead to the switchboard. Two methods of electrical oil-switch operation are in use. One is by means of solenoids and the other by means of

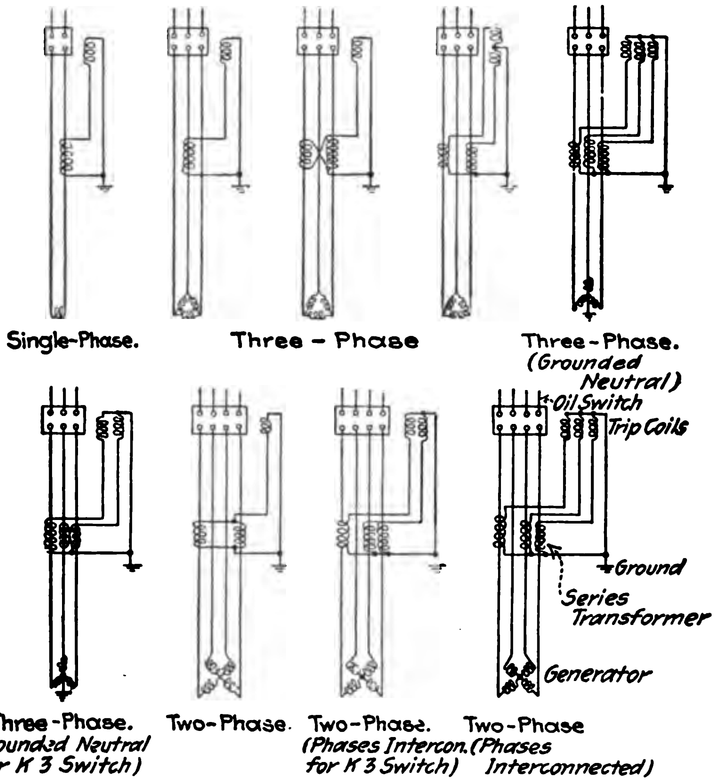


FIG. 84.—Trip Coils for Oil Switches in Connection with Series Transformers.

motors. Motor-operated oil switches are built by the General Electric Company, while the solenoid type is made by the General Electric, Westinghouse and other manufacturing companies.

3. Pneumatic oil switches are sometimes employed in place of motor-operated switches. Their manner of operation is much more complicated and not as safe as that of the other

types since they require special machinery to produce air pressure. The operation of the valves of the pressure cylinder on the oil switch, moreover, is not reliable. The following synopsis gives a survey of the action, operation, and manipulation of the various types of breakers in use. For relays see Chapter XVI. In the diagram of automatic circuit breakers there are included overload and underload switches for direct current.

METHODS OF OPERATION *

Without electric trip or With electric trip:

- **MANUAL**
  - On panel
  - On wall
  - Remote
    - On flat surface
    - In cell
    - On pipe framework
- **ELECTRICAL**
  - D. c. motor
    - Std. sw. [illegible]p mechanisms
    - H. S. forms
  - Solenoid
    - D. c. standard mechanisms
    - A. c. special switches
- **MECHANICAL**
  - Pneumatic
  - Float
  - Press reg.
    - Air
    - Liquid

AUTOMATIC CONTROL

- **Without series transformers**
  - Series trip — Direct relay / D. c. trip — With or without time — Constant / Inverse — Overload
  - Auxiliary trip — Push button / Low voltage — With or without shunt transformers or series resistance
- **With series transformer**
  - Depending on load in secondaries — Without relay
    - Direct / Trip a. c. — On panel / On shaft
    - Without time element — Instantaneous
      - Short-circuit / Overload — A. c. trip / D. c. trip
      - Reverse current D. c. trip
      - Reverse phase — A. c. trip / D. c. trip
      - Differential / Low voltage / Underload — D. c. trip
  - Depending on time element — With relay
    - With time element — Constant or inverse
      - Overload — A. c. trip / D. c. trip
      - Reverse current D. c. trip

Attachments:—

Auxiliary switches (Circuit opening)

Indicating switches (Circuit closing)

Interlocks
- Electrical
- Mechanical

For voltages up to 2500 series trips are used to open automatic oil switches, one for a double pole (single phase) and two for three or four-pole switches (three phase or quarter phase). (See Fig. 83.) The trips are in series with the side of

* David B. Rushmore, "Electrical Connections for Power Stations," A. I. E. E., May 28, 1906.

the switch which is to be protected. For higher voltages, series transformers are inserted in the line, whose secondary

ULTIMATE BREAKING CAPACITY OF OIL SWITCHES IN KW.
GENERAL ELECTRIC COMPANY.
FOR THREE PHASE.

Type or Form.	Rating.	Line Voltage.	Non-automatic.		Automatic.		Remarks: * Number of Poles and Throws, Operation.
			On Panel or Framework.	In Cells.	On Panel or Framework.	In Cells.	
	amp.	volts.	kw.	kw.	kw.	kw.	
K_3	100–200	1,200	5,900	....	2,350	....	Built: 2, 3, or 4 poles, single or double throw (in one oil vessel). Operated: Manual.
"	"	2,300	5,300	....	2,150	....	
"	"	3,500	5,000	....	2,000	....	
"	"	4,500	4,700	....	1,900	....	
"	300–500	1,200	6,300	....	2,500	....	
"	"	2,300	5,900	....	2,380	....	
"	"	3,500	5,600	....	2,200	....	
"	"	4,500	5,300	....	2,100	....	
K_2	300–500	2,500	5,900	6,800	2,380	2,740	Built: 1, 2, 3, or 4 poles, single throw. Operated: Manual or electrical.
"	"	6,600	4,600	5,300	1,820	2,100	
"	"	13,000	2,640	3,040	1,050	1,200	
"	"	1,500	2,050	2,400	825	1,000	
"	800–1000	2,500	7,700	8,800	3,100	3,550	
K_4	300	2,300	12,000	13,800	4,800	5,500	Built: 1, 2, 3, or 4 poles, single throw. Operated: Manual or electrical.
"	"	6,600	9,900	11,400	4,000	4,000	
"	"	13,000	7,500	8,650	3,000	3,450	
"	"	15,000	6,500	7,500	2,600	3,000	
K_6	300	22,000	....	6,170	....	2,480	Built: Single pole and single throw. Operated: Electrical.
"	100	22,000	....	4,570	....	1,840	
"	"	33,000	....	2,740	....	940	
"	"	33,000	....	7,410	....	2,970	
"	"	45,000	....	4,500	....	1,890	
K_7	50–200	600	3,500	....	1,400	....	Built: 2, 3, or 4 poles, single or double throw. Operated: Manual.
"	300	600	4,200	....	1,700	....	
"	50	2,500	3,500	....	1,400	....	
H_3	For all voltages, amperages, and kilowatts. Built: In single pole, single-throw units in cells. Operated: Electrical (pneumatic or manual as special).						

* The number of poles and throws built with one oil vessel.

windings actuate the trip coil of the oil switch. Fig. 84 shows the various connections for different phases. The number of

tripping coils used depends upon the size of the switch to be opened. The number of series transformers depends upon whether or not the load is balanced and the neutral of the machine by star connection is grounded, and also upon the number of phases. Transformers actuating tripping coils must not be connected to instruments with series and shunt-windings, such as wattmeters or power-factor indicators. Every oil switch is built for normal voltage and amperage, but must nevertheless be capable of interrupting the entire power which all the generators in parallel are capable of developing. The various types of oil switches are therefore constructed for given voltage and maximum breaking capacity without regard to their method of operation and action. The breaking capacity of the various types as made by the General Electric Company, Westinghouse Company, and Hartman Circuit Breaker Company are tabulated on pages 123, 125 and 126.

For single phase multiply the above figures for ultimate kw. breaking capacity by 0.75 and for two phase by 1.5. For oil switches used with a lower line voltage than given in the table, use kw. rating of the nearest voltage given. Maximum power rating of switches for intermediate voltage values can be found by interpolation. It is recommended by the General Electric Company that the voltage of oil switches mounted on the board shall not exceed 2500. The above switches are constructed for operation in plants where the normal full load of the generators in the whole system or section does not exceed the maximum given kw. rating.

Oil switches are constructed so that single, double, triple, or four-pole switches are contained in one oil vessel. Moreover, sets of two, three, or four single-pole switches in separate vessels can be operated as double, triple or four-pole switches by operating them through a common mechanism. The former are used for tensions up to 6600 volts and the latter with isolated phases for all higher and extra high voltages. If these switches are to be used as double-throw switches their number must be doubled, with exception of type K3 (G. E. Co.), which contains the necessary number of contacts and studs in one vessel. Two sets of operating mechanisms are necessary for each set of double-throw switches, which are interlocked mechanically or electrically so that it is rendered impossible to

ULTIMATE BREAKING CAPACITY OF OIL SWITCHES IN KW.
WESTINGHOUSE ELECTRIC AND MANUFACTURING COMPANY.

Type or Form.	Rating Amp.	Line Voltage	Kw. Rating.			Remarks: * Number of Poles and Throws, Operation, Installation.
			Single Phase.	Two Phase.	Three Phase.	
A	300	6,600	3,500	7,000	6,000	2, 3, or 4 poles, single throw. Operated: Manual, non-automatic. Mounted on panel or framework.
D	100–1000	3,300	600	1,200	1,000	2, 3, or 4 poles, single or double throw. Operated: Manual, non-automatic. Mounted on panel, wall, or frame.
B	20–1,200	3,300	5,000	10,000	8,500	2, 3, or 4 poles, single throw. Operated: Manual, automatic, or non-automatic. Mounted on panel or framework.
"	20–300	3,300–6,600	"	"	"	
"	20–200	6,600–11,000	"	"	"	
"	20–100	11,000–22,000	"	"	"	
C	600–2000	3,300	....	....	....	Single pole, single throw. Operated: Electric, automatic, or non-automatic. Mounted in cells.
"	600–1200	3,300–6,600	....	....	....	
"	600	6,600–13,000	....	....	....	
"	300	13,000–22,000	....	....	....	
"	200	22,000–33,000	....	....	....	
"	300	45,000	....	....	....	
"	200	60,000	....	....	....	
E	1,200	3,500	6,000	12,000	10,400	Single pole, single throw. Operated: Manual or electric, automatic or non-automatic. Mounted in cells.
"	600	7,500	"	"	"	
"	20–300	16,500	"	"	"	
"	20–100	25,000	"	"	"	
"	20–100	35,000	"	"	"	
G	100	60,000	115,000	230,000	200,000	Single pole, single throw. Operated: Electric, automatic, or non-automatic. Mounted in cells or without.
"	200	120,000	"	"	"	
L	50–200	60,000	12,000	....	20,000	Single pole, single throw. Operated: Electric or manual, automatic or non-automatic. Mounted in cells or without.
"	"	88,000	"	....	"	

* The number of poles and throws built with one oil vessel.

ULTIMATE BREAKING CAPACITY OF OIL SWITCHES IN KW.

Hartman Circuit Breaker Company.

Type or Form.	Rating Amp.	Line Voltage.	Single Phase.	Two Phase.	Three Phase.	Remarks: * Number of Poles, Throws, Operation, Installation.
A "	25–400 25–200	3,300 6,600	kw. 2,500 "	kw. 5,000 "	kw. 4,000 "	Single pole, single throw. Operated: Manual or electric, automatic or non-automatic. Mounted on panel or wall.
B	100–200	2,500	500	1,000	850	2, 3, or 4 poles, single throw. Operated: Manual, non-automatic. Mounted on panel or wall.
C " " " "	1200 25–900 25–400 25–200 25–100	1,100 3,300 6,600 15,000 22,000	5,000 " " " "	10,000 " " " "	8,500 " " " "	Single pole, single throw. Operated: Manual, wire rope, electric, automatic, or non-automatic. Mounted on panel or wall.
D	50	7,500	....	....	....	2 poles, single throw. Operated: Manual, non-automatic. Mounted on panel or wall.
F "	100–300 100–200	3,300 6,600	2,500 "	5,000 "	4,000 "	Single pole, single throw. Operated: Manual, non-automatic. Mounted on panel or wall.
G	100–200	3,300	500	1,000	850	2, 3, or 4 poles, single throw. Operated: Manual, automatic, or non-automatic. Mounted on panel or wall.
A.T.	25–400	6,600	2,500	5,000	4,000	Single pole, single throw. Operated: Manual or electric, automatic or non-automatic. Mounted on panel or wall.
E	.... Superse	45,000 ded by C.	.... and H.	.... switches	....	Single pole, single throw. Operated: Electric, automatic. Mounted in cells.
H	100	60,000	....	....	17,000	Single pole, single throw Operated: Wire rope, electric, automatic, or non-automatic. Mounted on wall.

These switches are used with a normal load of a system not exceeding one-third of the breaking capacity specified.

* The number of poles and throws built with one oil vessel.

close both throws at the same time. Each switch consists of three parts:

1. A frame holding the studs, contact pieces, and porcelain bushings.

2. A removable oil vessel mounted on the frame.

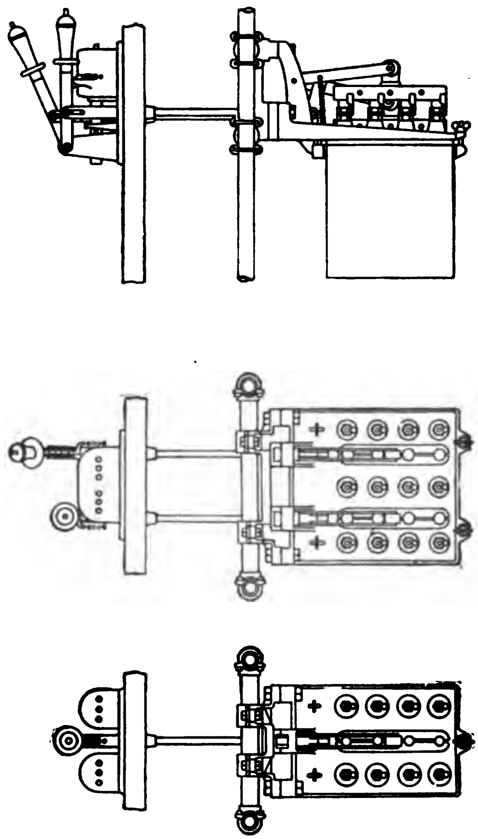


Fig. 85.—K3 Oil Switch Mounted on Pipe Supports Back of the Panel.

3. Movable contact bridges with operating devices.

The construction of type H3 (G. E. Co.) is an exception.

Fig. 85 shows a K3 four-pole double-throw switch with release mechanism, mounted on pipe supports back of the panel.

Cables or bar connections are led to the outside terminal of the poles at safe distances from all metallic parts. The wedge-

shaped copper bridges are fastened to wooden rods connected to the operating mechanism so that they can move through the frame. They are operated rapidly and simultaneously under oil. The oil vessel is lined throughout with laminated wood and is furnished with barriers of the same material, which are held securely in position between the poles of the switch. When the switch is to be tripped automatically, the tripping coil operates the linkage of the mechanism without moving the handle on the front of the board from its "closed" position,

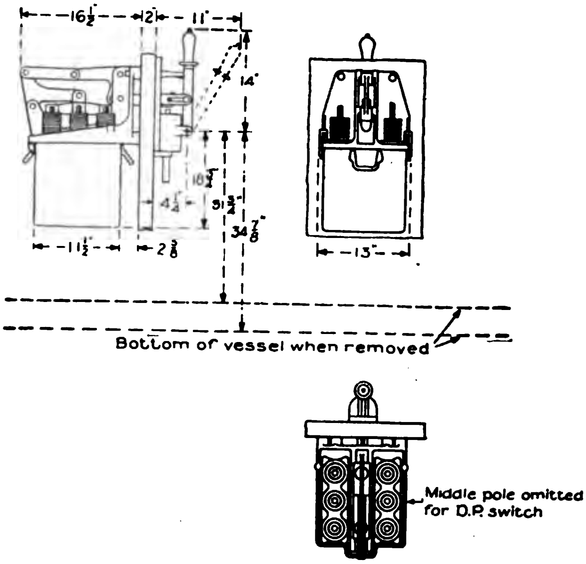


FIG. 86.—K2 Oil Switch.

which might otherwise injure the attendant. This action is made possible by the slot in the horizontal member of the mechanism on the front of the board. If, for instance, the operator closes a switch on a short-circuit or overloaded line, the tripping coil will immediately throw open the oil switch without throwing out the handle in the hand of the operator. Such switches are termed non-closable on overload. The position of mounting thus requires a base casting and extension link. In Fig. 86 we have one triple-pole single-throw K2 switch with electrical trip (one coil) for use with series transformer. For the double-pole single-throw switches, the middle pole of

the three-pole switch is omitted. Figs. 87 and 88 show methods of mounting double, triple or four-pole K2 non-automatic oil switches. They are mounted on the wall or in cells removed from the board. The mounting also applies to automatic

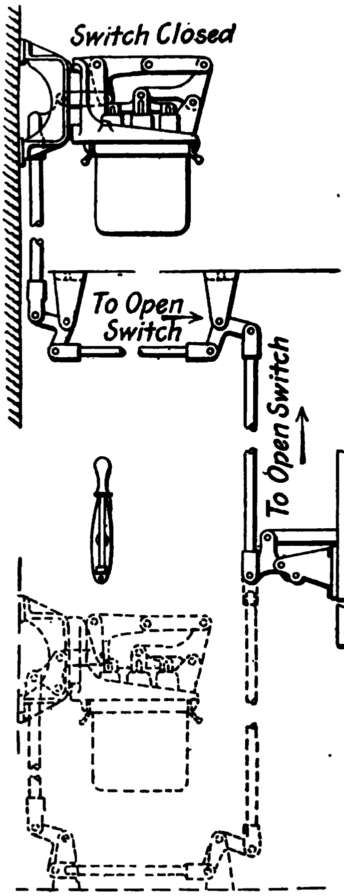


FIG. 87.—Pipe Mechanism for Operation of K and K2 Oil Switches.

switches. The method of mounting shown in Fig. 87 allows the placing of the oil switch in any position relative to the board. Care must be taken, however, that the length of compression members of the operating mechanism be not too great as otherwise bending will take place, so that the switch is

not completely opened or closed. Such members may be strengthened by guides or through increase in cross-section.

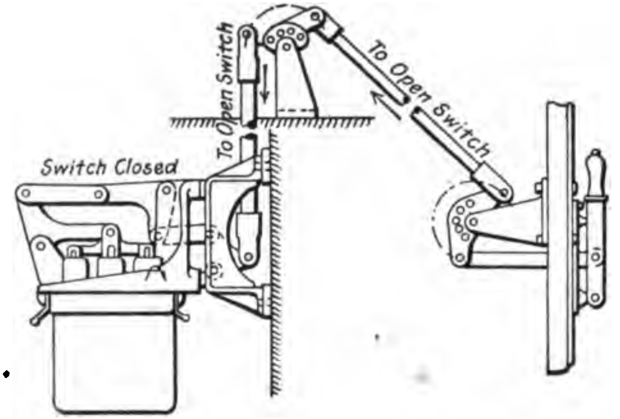


FIG. 88.—Pipe Mechanism for Operation of K and K2 Oil Switches.

FIG. 89.—Triple-Pole Single-Throw 15,000 Volt K2 Oil Switch for Remote Control. (Each Pole is Installed in a Separate Brick Cell Not Shown.)

Fig. 88 requires the mounting to be in a plane perpendicular to the back of the board at the center line of mechanism handle.

Fig. 89 is a photograph of three single-pole K2 single-throw switches for 15,000 volts and 300 amp., operated from the same mechanism by means of a common shaft. Each oil switch is mounted in a separate cell of brick or other fireproof material (omitted in the cut). The mounting of the cells and the corresponding switches relative to their control panel is such that the rod from the board operates the shaft between its bearings or immediately outside of one of the bearings.

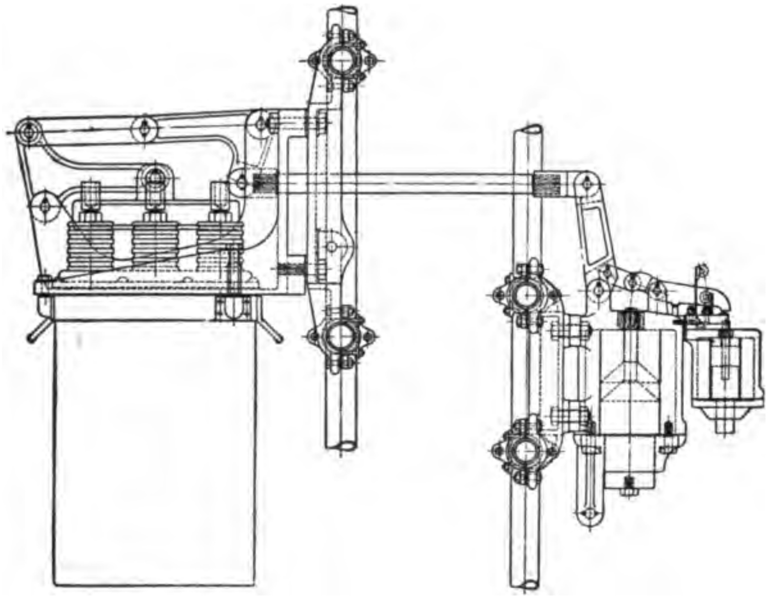


FIG. 90.—K2 Oil Switch Operated by Direct-Current Solenoids.

Fig. 90 shows arrangements for an electrically operated three-pole K2 oil switch. The switch and d.c. solenoid are mounted on pipe supports. Their relative position may be varied as desired, provided the necessary changes in operating mechanism are made. Sets of two, three or four single-pole switches in cells similar to those shown in Fig. 89 may be operated with common solenoids, in place of mechanical devices. Fig. 91 shows a triple-pole oil switch, type K4 with electric trip. For double pole, the middle pole of the triple-pole switch is omitted. The oil switches are mounted on the

board and are braced by two pipe supports apiece because of the greater weight and lever arm.

When mounting oil switches, provision must be made allowing removal of the oil vessel when the switch is open. In exceptional cases allowance can be made for removal of the vessel when the switch is closed, when special care in handling is necessary. This condition is fixed by the distance between the bottom of the vessel and the floor or cell bottom. The method

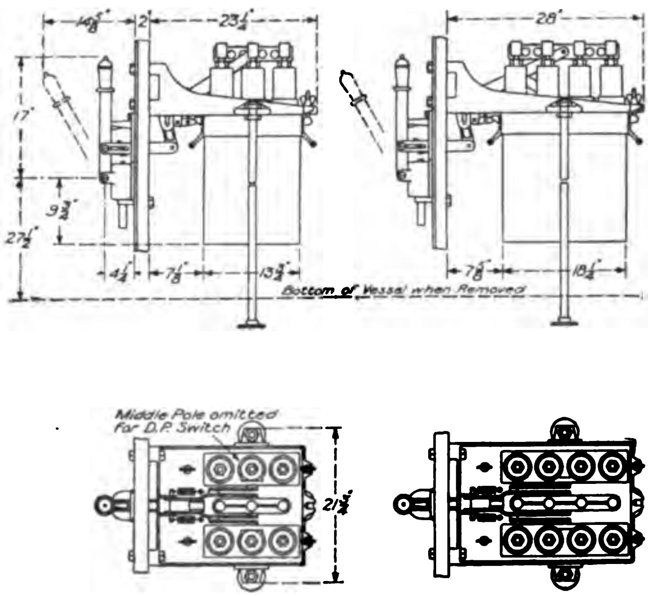


FIG. 91.—K4 Oil Switch.

of mounting a three-pole type K4 oil switch on pipe supports is given in Fig. 92.

Fig. 93 is a wiring diagram for a d.c. solenoid for operating an oil switch. It has two windings (see Fig. 90), the larger one (A) being the closing coil and (B) the tripping coil. A small double-pole controlling switch is mounted on the board, which controls the current for the opening and closing coils. A red bull's-eye lamp shows when the switch is closed, and a green one when it is open. On the solenoid there are also two small auxiliary switches 1 and 2. Switch 1 is open when the

oil switch is closed, that is, after coil A has operated. It is closed when the oil switch is open. The action of switch 2 is the reverse of that of switch 1. The object of each of the two auxiliary switches is to disconnect the coil with which it is in series, after this coil has operated, and at the same time to throw into circuit the coil of the other switch, thus preparing

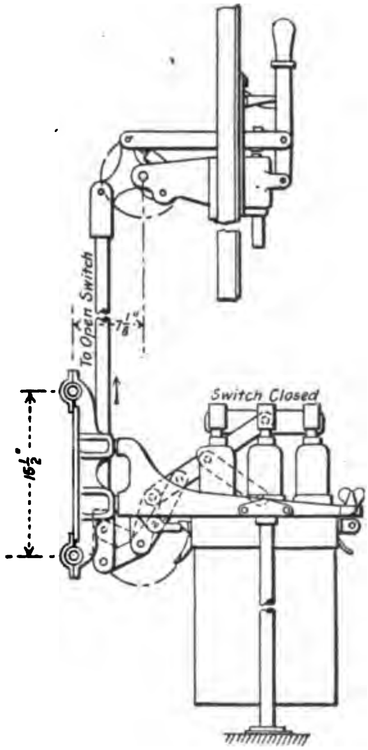


FIG. 92.—Pipe Mechanism for a K4 Oil Switch.

the solenoid for reversing, which is made possible by operation of the controlling switch. The auxiliary switches also operate the signal lamps. Resistance R is used only when the d.c. circuit for the operation of the solenoids has an e.m.f. over 125 volts. The solenoids and lamps are protected by the fuses F and f. The opening coil B is smaller because the weight of the contact bridge helps to open the oil switch. The diagram is for non-automatic operation.

When oil switches are to be used as double-throw switches, as is the case when transferring connections between busbar sets, the simultaneous closing of both throws must be prevented. For mechanically or electrically operated switches

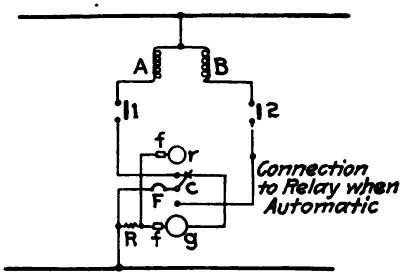


FIG. 93.—Diagram of a Solenoid Operated Oil Switch.

this is provided for in the mechanical or electrical interlocking devices.

Fig. 94 is a wiring diagram for two electrically interlocked solenoid mechanisms for the operation of two oil switches. A_1 and A_2 are the closing, and B_1 and B_2 the opening coils.

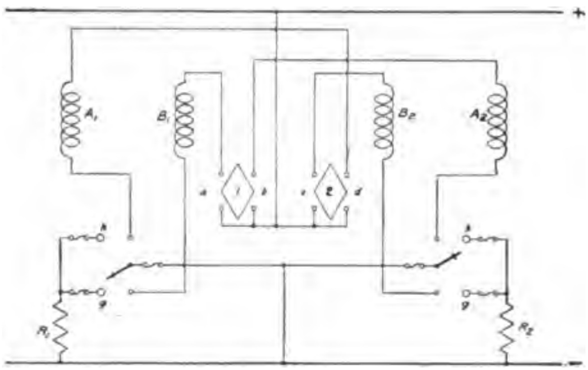


FIG. 94.—Diagram of Two Interlocked Solenoid Operated Oil Switches.

Auxiliary switch 1 closes the side *a* when the oil switch U_1 is closed. Similarly switch 2 closes side *c* when switch U_2 is closed. Switch 1 closes side *b* when U_1 is open, and switch 2 closes side *d* when U_2 is open. Consider for example that U_2 is closed, as indicated by the red lamp A_2, and that C_2 is in the upper position. Then switch 2 will close side *c*. If we now at-

tempt to close switch U_1 we will throw C_1 into the upper position in order to excite coil A_1. But d of switch U_2 is open. Therefore A_1 is not in position to close U_1, and therefore U_1 cannot be closed. This shows that both switches cannot be closed at the same time, but that they can be opened together. In Fig. 94 both switches are non-automatic.

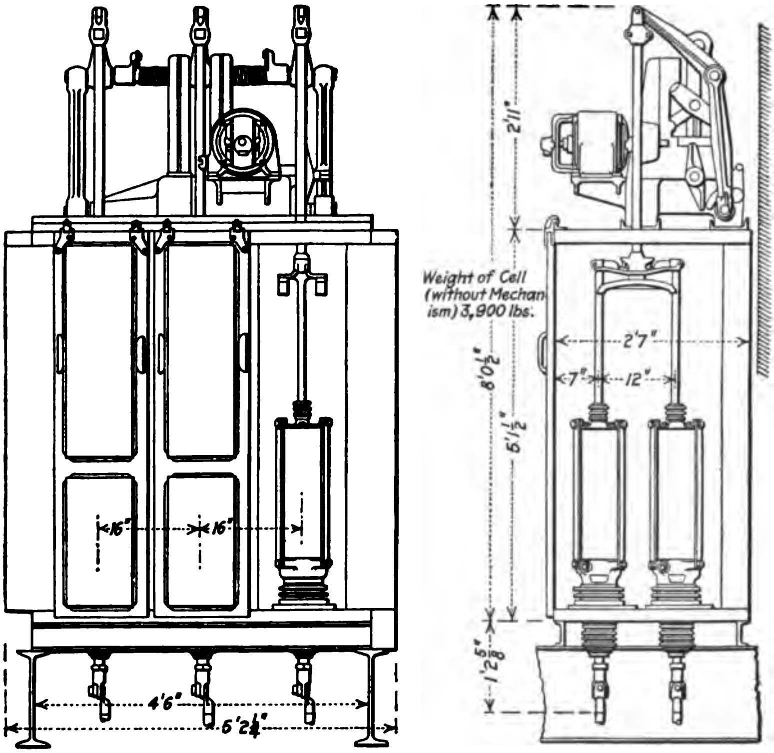


FIG. 95.—Motor Operated H3 Oil Switch.

The General Electric Company recommends types H3 and H4 oil switches for the largest stations with any voltage. (See Fig. 95.) These switches are distinguished from all other types by three characteristics. Each terminal of a pole pair is contained in a separate oil vessel, the outside terminals are on the bottoms of the vessels instead of the top or side, as in other types, and finally the switch is operated by a d.c. motor. Each pole pair is mounted in a separate cell, three such cells con-

stituting a three-pole switch. Since each pole is inclosed in a separate vessel the arcs at the points of interruption are separated, which increases the safety of the device. Since the cable connections are made at the bottom of the vessels they are separated from all movable parts, affording better insulation and easier access. The metal plungers which project

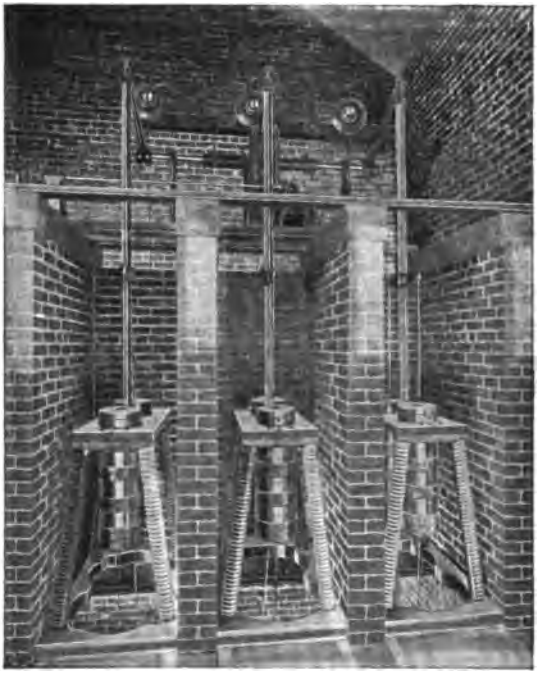


FIG. 96.—Motor Operated H3 Oil Switch for 60,000 Volts.

through the top of the insulators are connected to a metallic cross arm, which in turn is joined to the operating mechanism by wooden rods. The operating height of the plunger is 12 in. for 6000 volts, and 17 in. for 12,000 volts. All poles open simultaneously, six arcs being formed in the three-pole switch. The cells inclosing the switches are made of brick. The top and bottom are slate, the bottom containing the insulators for the cable connections. The motor operation has an advantage over the solenoid method in that it operates the switches more rapidly than the solenoid under lower service voltage. The

above illustration shows an H3 switch for 15,000 volts, good for 1200 amp. The oil vessels are made of brass or sheet steel lined with insulating material. For 60,000 volts and over, the vessels are made barrel-shaped, and are constructed of wood, held together by rope windings, being supported in the cell on four insulated legs. (See Fig. 96.)

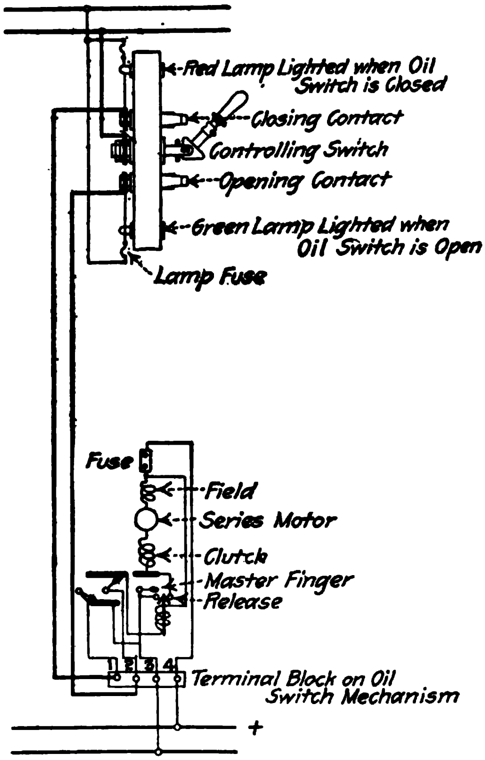


FIG. 97.—Connection of Controlling Circuits for H3 Oil Switch with Magnetic Release. (Using Double-Throw Controlling Switch, Normally Open with Double-Throw Contact Fingers.)

Fig. 97 is the wiring diagram for the motor of an H3 oil switch. Its operation consists essentially in winding up two spiral springs after each throw of the switch. Opening of the oil switch is entirely independent of the motor. A control switch or relay on the board controls the circuit of an electric magnet operating a toggle. This toggle releases the spring

which operates the switch, simultaneously starting the motor to wind up the springs.

The floor where the cells are set up requires special construction on account of the cell weight and the cable connections on the bottom of the cell.

Westinghouse oil switches may be classified in two groups, the first comprising those in which the interrupting device is similar to a knife switch, so that each pole pair is interrupted on one side only, the second group including such forms where

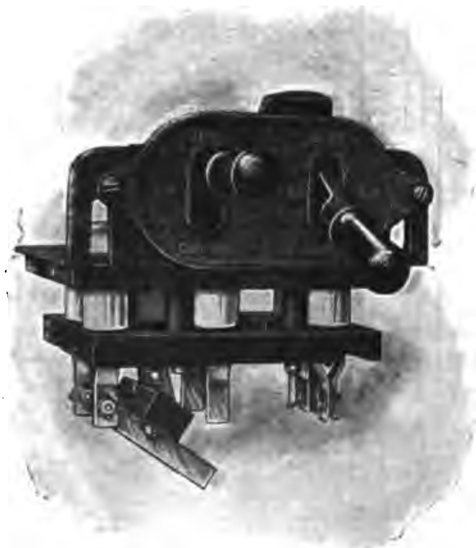


FIG. 98.—Type D Oil Switch with Removed Oil Can.

there is interruption at both terminals of each pole pair. The company styles the first type as oil switches, and the second as circuit breakers. The A and D switches constitute the first group, and all others the second. A view of type D mounted on the back of a panel is given in Fig. 98. Insulating barriers are fastened on the cover between pole pairs, which guard against the establishment of current between terminals of different potential. Current interruption takes place under oil, in an oil vessel common to all the poles. It is built of metal lined with insulation. The several knife blades are connected together by a specially treated wooden piece which is

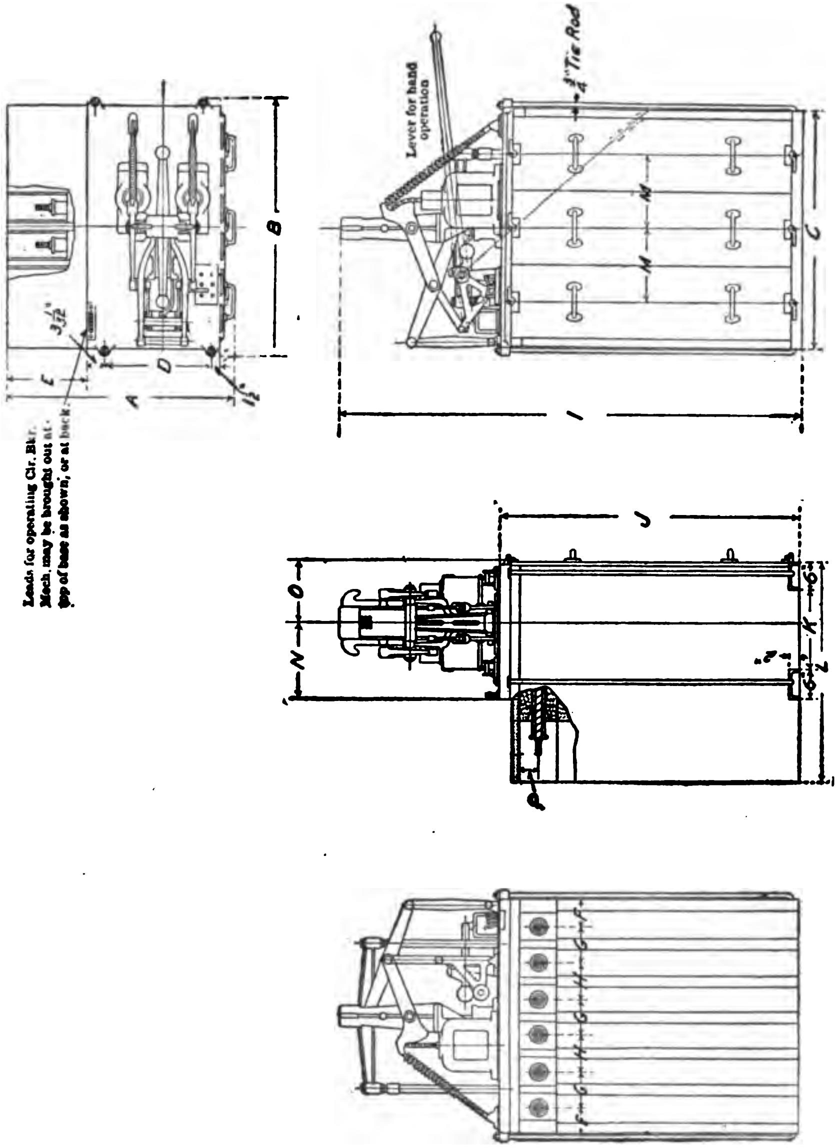


Fig. 99.—Type C Oil Switch Electrically Operated Distant Control.

itself connected by a rod of the same material to the operating lever. Each switch blade of type A requires a separate rod, all the rods being operated by the same mechanism. In type B, each pole has a separate tank lined with insulation. All tanks, terminal insulators, and operating mechanisms are carried on a cast-iron frame fastened to the switchboard or wall. The tanks and rods carrying the contacts serve as barriers between the points where arcing may occur. At over-

FIG. 100.—Type C Oil Switch Electrically Operated Distant Control.

load or short-circuit the tripping coil which opens the oil switch releases a trigger, so that the handle is not thrown open. For voltages above 6600 volts it is advisable to ground the metallic framework of the breakers, and in cases where the power is more than 4000 kw. per circuit it is the best practice to operate the oil switch apart from the switchboard. For higher voltages and larger power the Westinghouse Company makes use of type C switches electrically operated and mounted in fire-proof cells. It is used under conditions similar to those where types K6 or H3 or G. E. make would be used. Figs. 99

and 100 show the outlines of the cells and the operating mechanism and a view of the switch proper. Each cell contains one pole pair in one oil tank, which is easily removable. The contacts are mounted on large porcelain insulators. The leads

FIG. 101.—60,000 Volt Automatic Oil Switch, Type C.

are brought out at the rear of the switch and may pass directly into a masonry conduit. Fire-proof insulating barriers are provided between phases on the back of the cell, and smaller barriers of slate or asbestos are placed between cables of the same phase. The oil tanks are constructed of heavy sheet metal, the interior being lined with insulating cement, which

is molded in such a form as to fit closely about the terminals and moving contact piece. By this means the necessary amount of oil is reduced to a minimum. The contact bridge is carried by a wooden piece, which at the same time serves as

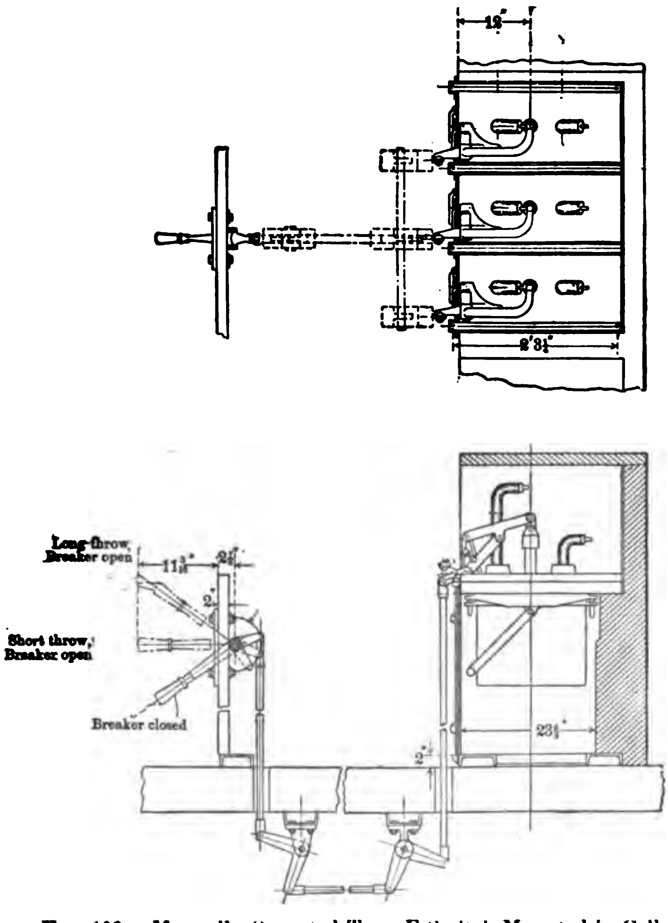


FIG. 102.—Manually Operated Type E Switch Mounted in Cells.

a barrier between the poles. These wooden rods are fastened at their upper ends to a wooden cross bar, which through a system of levers is raised by means of the closing solenoid core, assisted at the beginning of each motion by a pair of balancing springs. Oil switches of this type are operated by means of solenoids, requiring a 125-volt direct

current. A control switch governs the operation. Tell-tale indicators and red and green signal lamps are used to indicate the open and closed positions of the oil switch. The break in these switches occurs near the surface of the oil instead of in the lower portion of the tank as in type H3. For voltages of 45,000 to 60,000 volts form C, as shown in Fig. 101, is used. The movable contacts are on a U-shaped piece, which is attached to a rod of treated wood whose upper end is connected to the

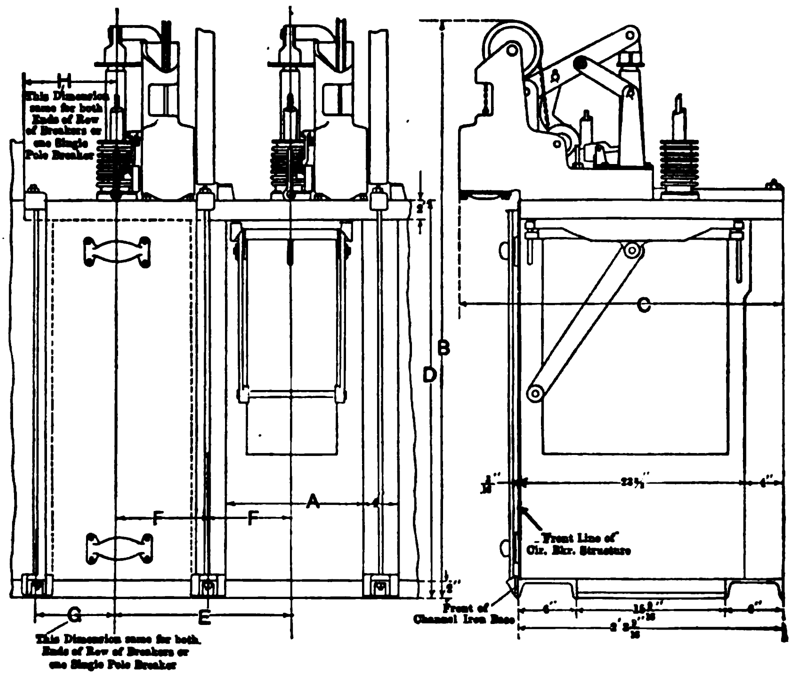
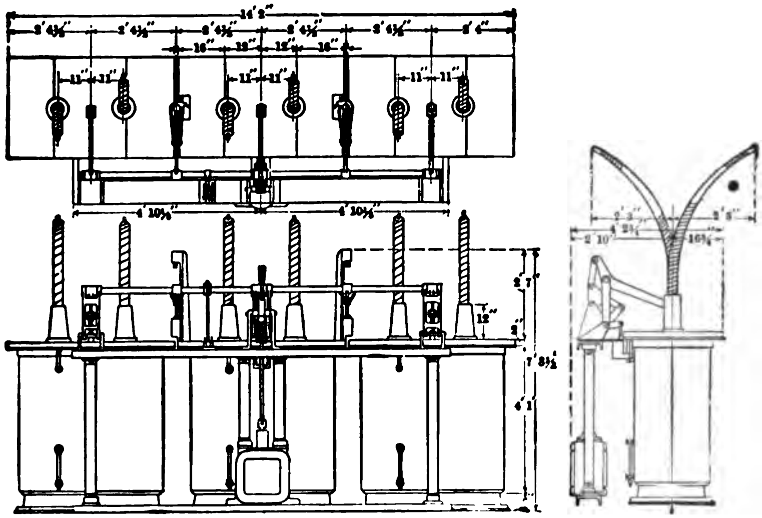


FIG. 103.—Type E Oil Switch Electrically Operated.

operating mechanism. The fixed contacts are mounted on heavy porcelain bushings carried on wooden brackets beneath the surface of the oil. A double barrier of alberene stone is placed between the contacts and extends entirely across the oil tanks. Between the two parts of this barrier is placed the wooden rod carrying the U-shaped contact piece, which moves in slots cut through the barrier. The oil tank is of copper, rectangular in shape and is fitted in a masonry cell. Inside the copper tank is a bottom of treated wood, and there is also a

framework on the sides. This wood acts as a support for the second lining, which is of alberene stone and covers the entire surface. The control and operating apparatus are the same for all electrically operated oil switches. The upper part of the cement work is omitted in the illustration.

Fig. 102 is a manually operated type E switch, mounted in cells. It is provided with an automatic tripping coil. A toggle joint operates a horizontal shaft from which the switches are



The height over all is 9 feet 10 inches.
540 gallons of oil are supplied to fill the tanks.
Weight with oil, 15,000 pounds.
Boxed weight, including weight of oil, 16,500 pounds.

FIG. 104.—Type G Oil Switch Electrically Operated for 60,000 Volts.

operated together through separate rods. These rods are placed in the front of the cell between the doors. Type E switch is built single-pole and is mounted in separate cells, being fastened to the slate or soapstone cell cover. The same type of switch with electrical operating mechanism is shown in Fig. 103. The single-pole switches are similar to the manually operated type E switch, and are similarly mounted on the covers of the cells in which they are contained. Each switch has its own solenoid mounted on the cover, but they

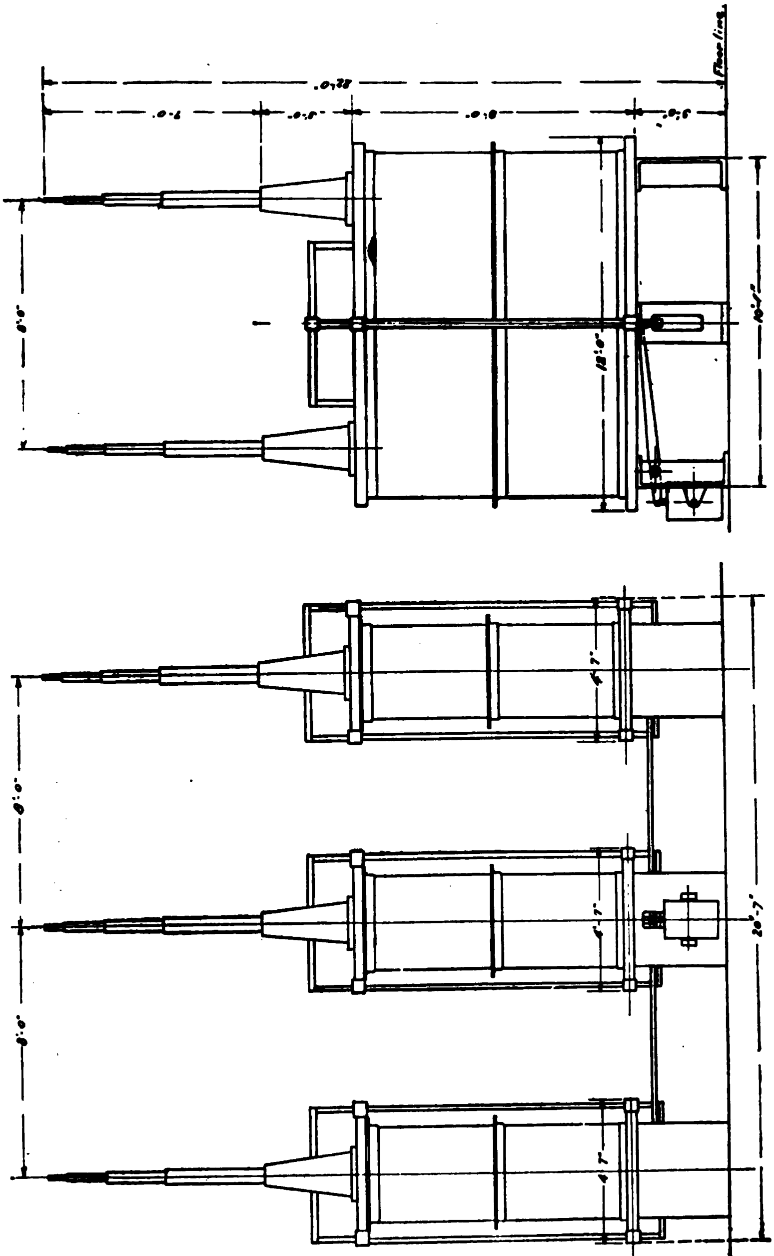


FIG. 105.—Type G Oil Switch Electrically Operated for 120,000 Volts.

are all simultaneously operated from a single control switch on the board.

In Fig. 104 we have a set of three single-pole, type G oil switches, built for 60,000 volts. They are operated by a com-

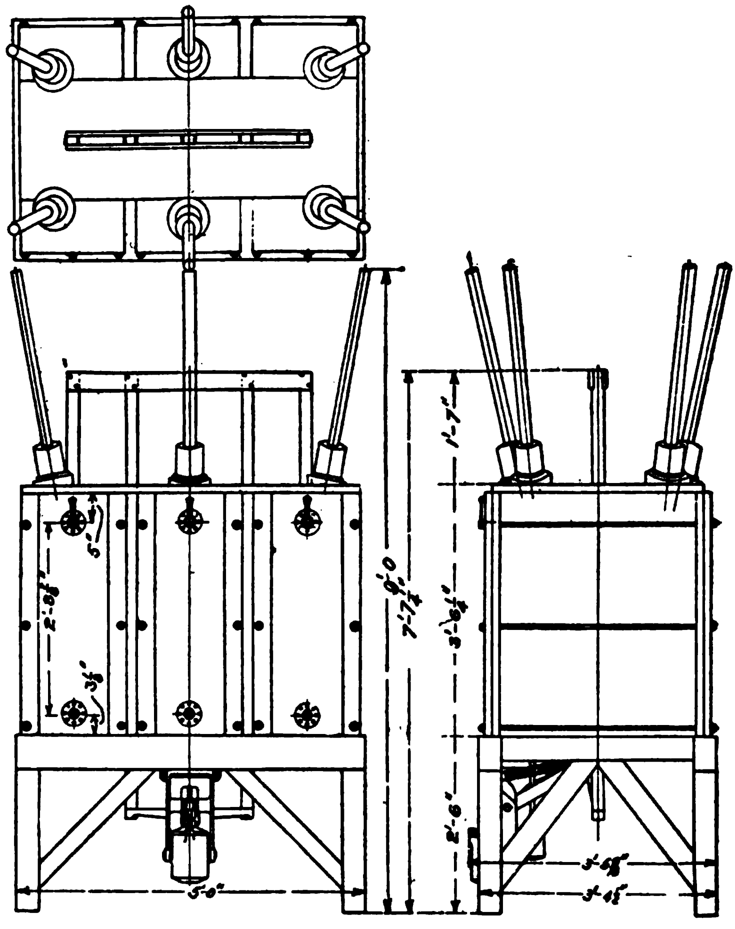


FIG. 106.—Type L Oil Switch Electrically Operated for 60,000 Volts.

mon solenoid mounted at the foot of the cell; the tanks, of which (1) for each switch are made of boiler steel lined with insulation. Poles in the same tank are separated by insulating barriers. The heavily insulated cable terminals project about 4 ft. 6 in. above the top of the cell. The three

vessels may be mounted in cells or on iron frame supports. The cross piece operated by the solenoid is connected to three

FIG. 108.—Type B Three-Pole Non-Automatic Oil Switch.

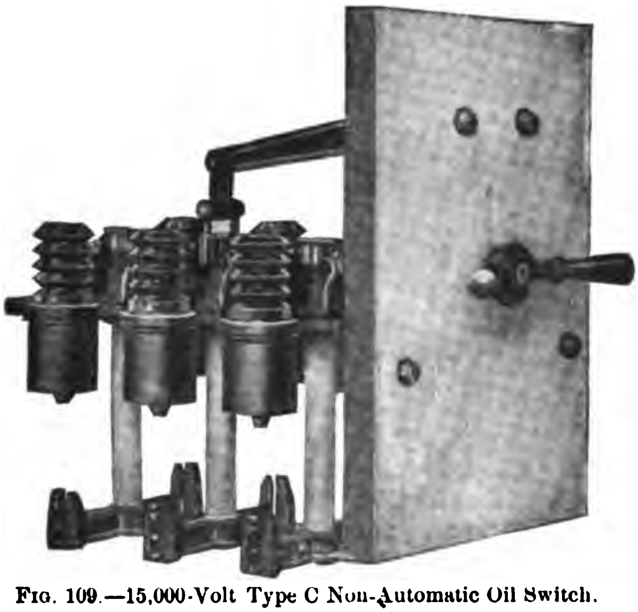


FIG. 109.—15,000-Volt Type C Non-Automatic Oil Switch.

sets of toggles which operate the wooden rods of the U-shaped contact bridges.

Fig. 105 is a set of three single-pole type G oil switches for 120,000 volts. The boiler steel tanks are supported on iron framework. All three switches are operated by one solenoid through a cross arm and rod. The tanks are separated from each other by a certain distance.

Fig. 106 shows the outlines of a type L oil switch for

FIG. 110.—Three-Pole Type C Automatic Oil Switch for Wall Mounting and Remote Table Control. (Shown with One Switch and One Transformer Tank Removed.)

88,000 volts, which is operated either manually with toggles or electrically. The distance of contacts above the cell when the switch is open is 17 in. for a 60,000-volt switch, and 20 in. for 88,000 volts. The tanks are made of hard wood, covered with metal sheeting. In each tank there is a double barrier between the poles, and the contacts are fastened to bushings in the middle of each of the two resulting chambers. A mov-

able rod between the barriers operates the contact bridge through the slots cut into the barriers. The solenoids are mounted on the lower part and operate the rods of the contact bridges through the cross arm and toggle mechanism. In all of the last-mentioned switches, heavily insulated cables project

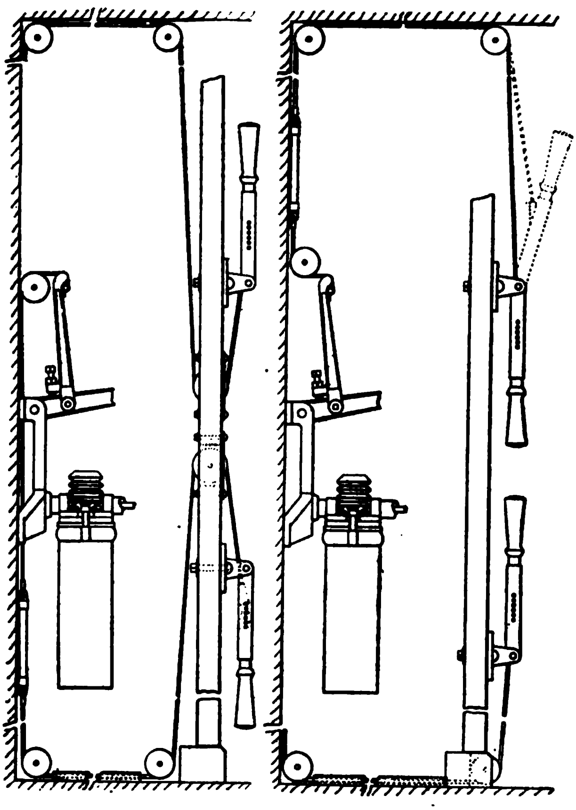


Fig. 111.—Table Contact for Types C and H Oil Switches.

from the bushings in the cover, to which the circuit connections are made. These switches can be opened automatically or non-automatically, as shown by the table for Westinghouse switches. Special appliances for automatic interruption will be discussed in the chapter on relays.

The scope of this treatise does not make it possible to discuss the products of all manufacturers of oil switches. Only those

have been selected which are most used in service, and their special characteristics have been emphasized. Some of the products of the Hartman Circuit Breaker Company also deserve mention. The oil tanks of switches of this company are made of molded fiber, so that a good separation of both poles is attained with the aid of the rods carrying the contact bridge.

The pole pairs of a switch type A are in separate oil tanks, and the whole switch, including operating mechanism and auto-

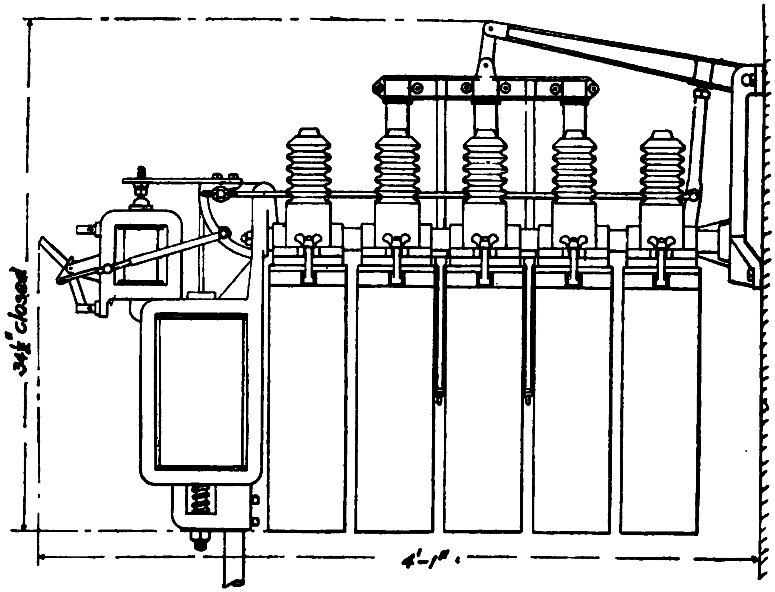


FIG. 112.—Type C Oil Switch Electrically Operated for 22,000 Volts.

matic tripping coil, is carried on two pipes fastened to the switchboard. For low voltages and small capacity, all three-pole pairs are placed in one tank. (See Fig. 108, type B.) Effective barriers against arcing are found in the extra wooden rods between the phases and the operating rods for each pole pair. Up-and-down motion of the rods is brought about by a crank-like motion of the operating mechanism. Fig. 109 is the type C for 15,000 volts with tanks removed. The covers of the tanks together with the bushings are made of treated fiber. The illustration shows the movable laminated contacts

of jaw type and the wedge-shaped fixed contacts which fit into them.

For a.c. series arc circuits type D oil switch is used in place of plug switches. It is a double-pole switch in one tank similar to type B, Fig. 108. For high tensions type C is used, which is operated electrically from the board or by a wire rope arrangement. Fig. 110 illustrates a three-pole switch with two series transformers inclosed in tanks similar to oil-switch

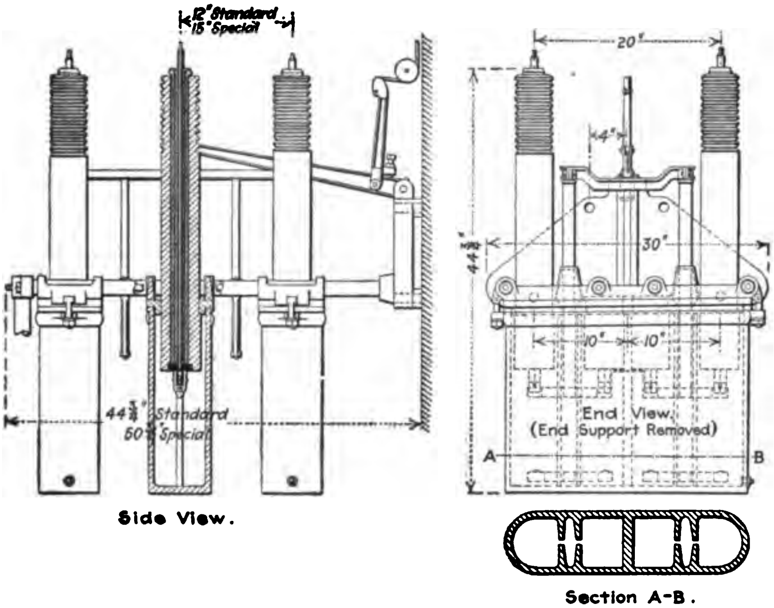


FIG. 113.—Type H Oil Switch Cable Control for 60,000 Volts.

tanks. In the illustration, one of the pole-pair tanks and one of the transformer vessels are removed. The outer vessels are the transformer tanks. The entire apparatus is carried on two pipe supports. Arrangements for wire rope operation, and electrical manipulation are shown in Figs. 111 and 112. In both cases the switches are mounted on a distant wall.

The type H switch is built for 60,000 volts. Instead of a double-break, a quadruple-break is used. (See Fig. 113.) Two auxiliary poles are supplied for each pole pair, and the two contact bridges are operated mechanically by two rods. The treated fiber tanks are fitted with barriers and projections,

which, with the movable rods, afford separation of the poles and auxiliary poles. This oil switch, like the type C, is operated electrically or by wire rope, and can be opened automatically or non-automatically. The fiber sleeves carrying the contacts are high and quite thick.

The Pacific Electric and Manufacturing Company produces

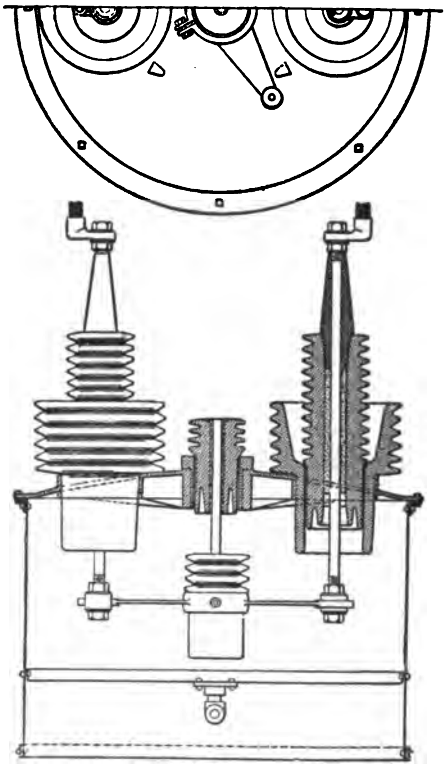


Fig. 114.—Oil Switch.

an oil switch for high tension in which each pole pair is actuated by a double contact arm revolving about a vertical axis. Fig. 114 shows a section and outline of one of these switches for 60,000 volts. The contact arm is mounted on a bushing on the lower end of a vertical operating rod. The outer ends of the contact arm connect with the poles which are joined to the circuit leads. Two or three of these switches may be manually operated as two or three-pole switches. If the

angle of rotation of the arms is made 90°, an extra-long interruption of phases is obtained.

The construction of oil switches is based on the following points: They interrupt the current under oil, the interruption with one phase being either single, double, or manifold. Since in the latter case the breaks are in series, the construction for high voltages can be quite compact, and the interruptions are positive and direct. High insulation of phases and poles of the same phase must be maintained, the phases for high tensions being broken in separate tanks. "Freezing," or sticking of contacts at the instant of operation, must be guarded against, and it must be possible to operate an electrically operated switch, manually, with a reasonable degree of safety. The oil as mentioned above must be of good quality, forming no sediment. This is of particular importance in the H3 type where the terminals are on the bottom of the tank. It should be possible to fill the tank without taking the switch apart, or disconnecting it from service. It is, however, advisable to fill the tank when the apparatus is not in use on account of the danger incurred in handling a live switch. In order that repairs may be undertaken provision must be made to disconnect the switch from all live parts. This is usually provided for by a disconnecting switch between the oil switch and the line. All live parts, such as studs, cable terminals, or copper rods projecting from the vessel must be wound with good insulation, or must be screened in order to obviate the dangers due to touching, fire, and short-circuit. The cells should have fireproof doors.

CHAPTER XVI

RELAYS

In large plants with expensive apparatus and where the service is continuous, it is necessary to protect the apparatus and machines by making provision for automatic current interruption. Such provision is also necessary to protect stations or a series of substations against serious shut-downs. The desired result is attained by equipping the apparatus, like oil switches, with tripping mechanisms which are operated by relays at certain critical moments. The relay itself is operated by the current which it is to interrupt, while the solenoids of tripping devices are energized from the secondary windings of series or shunt transformers, which are on the main circuit or from an independent source. They are adjusted to a predetermined condition of operation. Their action is the opposite of that of telegraph relays. With the latter, a strong current is required to operate the receiving apparatus, while the former open their switches with a relatively weak current, as it would be difficult, if not impossible, to operate the relays directly with the main current when this current assumes large proportions. A classification of relays may be made on the basis of current influence and kind of action:

Current Influence	*Action Time Element*
1. Overload for a.c. or overload relays.	Instantaneous. Time limit. Inverse time limit.
2. Reverse-current relays for a.c. with voltage winding.	Instantaneous. Time limit. Inverse time limit.
3. Reverse-phase relays.	Instantaneous.
4. Underload relays.	Instantaneous.
5. Low-voltage relays.	Instantaneous.
6. Reverse-current relays for d.c.	Instantaneous.
7. Over-voltage relays.	Inverse time limit. Instantaneous.

1. An overload relay, as the name indicates, serves to protect the line apparatus, or machines, against a load in excess of a given maximum. Such relays are made to act instantaneously at the points of energy consumption, especially when fire risk is great, in feeders which will deliver an excessive current under short-circuit or overload. In this case, an instantaneous interruption is preferable to a momentary disturbance, and this action at the place of consumption relieves the other time-limit or inverse-time-limit relays. Instantaneous overload relays are often used to prevent the current from ex-

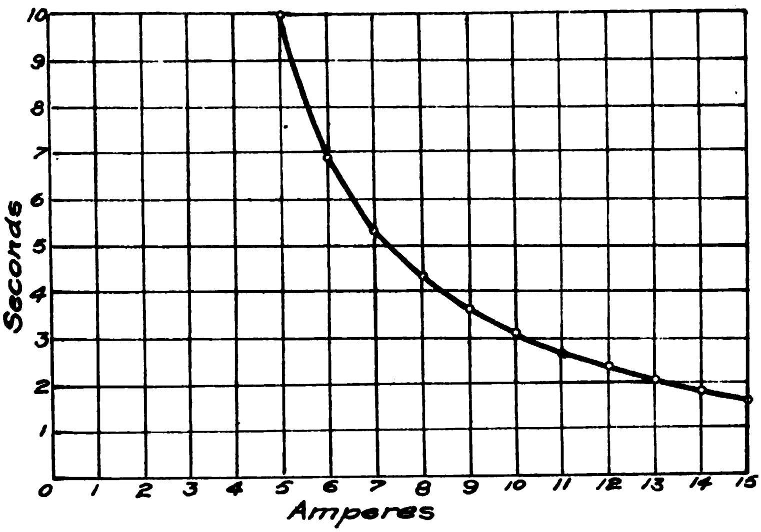


FIG. 115.—Ampere-Time Curve for Bellows-Type Overload Relay.

ceeding the maximum current rating of instruments. A time-limit relay maintains the service of the line in which it is connected, without regard to any danger, for a certain limited period. A device of this kind allows all the less important lines to be cut out by the instantaneous or inverse time-limit relays before it itself interrupts the main circuit. When the main current is interrupted it shows that the cause of interruption was not momentary or subject to recovery after a short time, such as strong currents caused by load variations or a burning out short-circuit, and that the cutting out of the less important lines has not sufficiently relieved the main circuit. Synchronous converters are protected on the a.c. side by in-

serting time-limit relays on the high-tension side of the transformers. It is recommended by some engineers to insert them in the feeders on the substation side, their action being made independent of the current direction. A special type of relay is that mentioned above, in which the time before action is inversely proportional to the amount of overload, so that the greater the overload the quicker will be the action of the relay, being instantaneous at short-circuit.

Fig. 115 is the ampere-time curve taken from a paper by G. F. Chellis,* for a bellows-type overload relay. This curve was obtained by adjusting the device to operate with 5 amp. in 10 seconds. The current was then increased step by step, and the times for the relay to operate were noted. This type of device has the advantage of disconnecting the feeders consecutively, so that the feeder nearest the source of disturbance receiving the greatest amount of current disconnects first, thus relieving the other feeders and relays. If the relief is not sufficient, the next relay disconnects, etc. Another method of securing consecutive operation is obtained by adjusting the definite time-limit relays to different time elements, in such a way that the farther a relay is from the source of power, the shorter is the predetermined time element. Fig. 116 shows the adjustment of overload, inverse time-limit relays between the power station of the N. Y. Edison Co., Waterside No. 1, high-tension busbar and the substation direct-current busbar. According to Chief Engineer Mr. Philip Torchio, the adjustment is as follows: Non-automatic oil switches are employed for the generators, as reliance is put upon the attendant to disconnect the generators by hand operation of the oil switches, whenever he finds it necessary to do so. To guide him, an overload relay, operating signal lamps, is mounted on each generator. This relay is without time limit. On each high-tension feeder in the generating station is mounted an overload relay with a variable time limit in inverse proportion to the value of current. Curve No. 1 shows the characteristic curve of this type of relay, the periods at which it is adjusted, and its relation in time and load to other similar relays at the substation end of the feeder. The feeder switch in the substation is automatic and is controlled by a relay similar to the one at the Waterside end of the feeder. The adjustment is shown in curve 2. The high-tension side of

* G. F. Chellis, "Time-Limit Relays," Pr. A. I. E. E., May 16, 1905.

the synchronous converters is equipped with a relay of the same kind as previously discussed, the calibration being shown in curve 3. The d.c. side of the synchronous converter is equipped with a reverse-current, inverse time-element, direct-current relay, the adjustment of which is shown in curve 4,

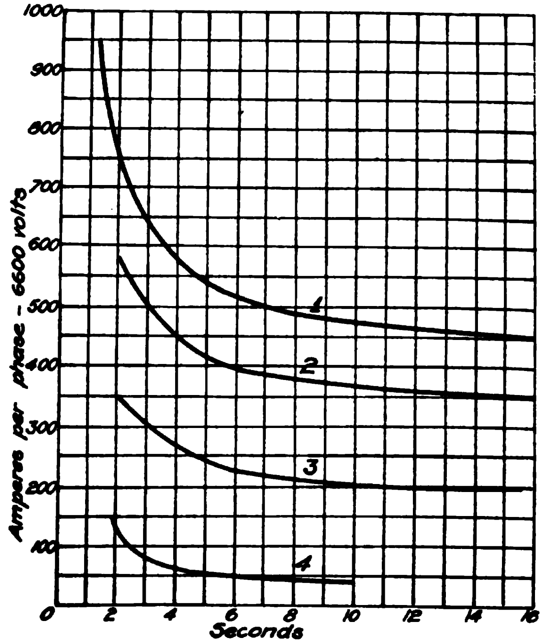


FIG. 116.—Relative Adjustment of Overload Inverse Time-Limit Relays between Waterside No. 1 High-Tension Busbars and Substation Direct Current Busbar.

which is figured on the basis of primary amperes for the purpose of comparison with the curves above it. The consecutive operation of the relays is plainly evident from a comparison of the four curves.

2. A reverse-current relay is one which acts on reversal of energy flow. It consists of two windings, in series and shunt with the line, respectively, so that one depends on the current, and the other on the voltage of the line. Under normal conditions of the line only the difference in the magnetomotive force of the windings acts. On reversal of energy, however, the sum of the m.m.f. of the two windings comes into action, and

the relay operates the switch. The ideal device of this type should possess the following characteristics. It should operate on overload at normal pressure, on short-circuit at zero or reduced pressure, or when the direction of the flow of energy is reversed. As a matter of fact it meets only some of the above conditions, and these only to a certain degree. The application of such relays therefore becomes limited. They are used here and there for the operation of generator oil switches or at the substation ends of feeders, but they are not reliable. The disadvantage is that, being dependent upon the e.m.f. supplied from the line, a condition will arise at a time of severe short-circuits when the e.m.f. will drop to a very low value, in which case the relay will lose its reverse feature and operate as an overload relay with a high setting. This brings about the action of all overload relays on parallel circuits, causing a shut-down. This disadvantage was sufficient to cause the Interborough Rapid Transit Company, of New York City, to replace their instantaneous "differential" relays, as they are also called, in the substations of the Manhattan Division by straight over-load time-limit relays. In other cases inverse time-limit relays have been recommended to take their place.

3. Reverse-phase relays are used to open motor switches not properly connected. They are useful for the protection of elevator motors or in any case where change of phase rotation is objectionable.

4. The object of the underload relay is to throw out one or more machines for load values under an economic load-factor, at which the remaining machines can run economically.

5. Low-voltage relays are used for motor switches, to insure proper control connections in starting. In connection with d.c. circuit breakers they are used for interrupting the circuit when the voltage drops to 50 per cent. of the normal value. (See Chapter IX.)

6. Automatic d.c. circuit breakers are often equipped with a reverse-current relay inserted directly on the circuit breaker or in the feeders. Its object is to prevent the synchronous converter from running away when its field circuit is opened, in which case it is used in connection with a speed limit device. It is advisable to have the relays independently energized by a battery or exciter for, under short-circuit or overload, it may

occur that the relay refuses to act on account of the low voltage. These relays are especially adapted to protection against current reversal in an installation where the line is fed by storage batteries and converters.

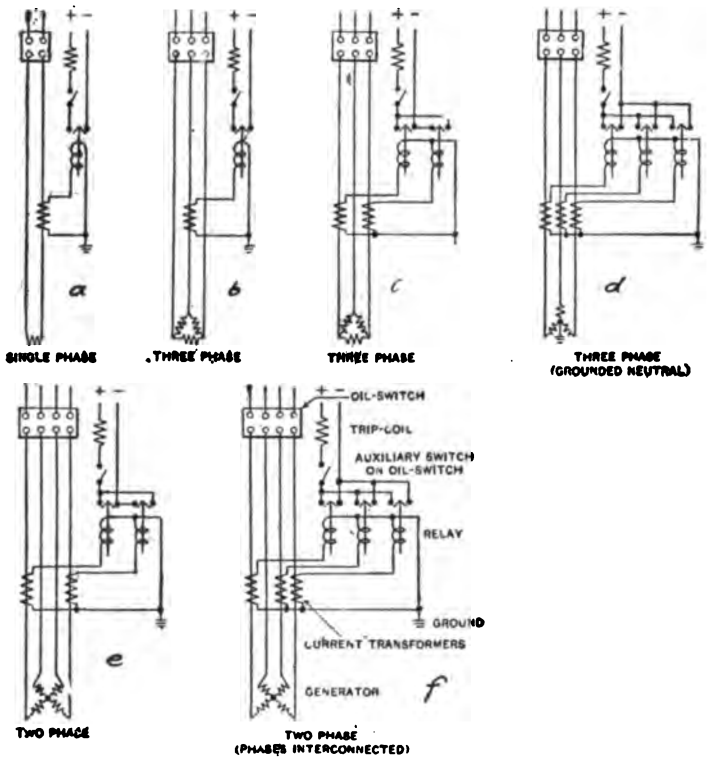


FIG. 117.—Connections of Oil Switches with Trip Coils Operating on Direct-Current Circuit Using Circuit-Closing Relays.

7. Over-voltage relays are used in connection with storage batteries.

In regard to the action of a.c. relays, they may either close a d.c. auxiliary circuit for energizing the trip coils, or they may open an a.c. auxiliary circuit which under normal condition is kept short-circuited by the relay. In the first case the auxiliary d.c. is independent of the main current, its source being a battery, exciter, or d.c. generator, of 125-250 volts. In the second the current is supplied by the secondary winding of

a series transformer, inserted in the main line which at the same time operates the relay.

In Fig. 117 there are shown the connections of oil switches with trip coils operating on a d.c. circuit using circuit-closing relays. The number of poles corresponds to the number of

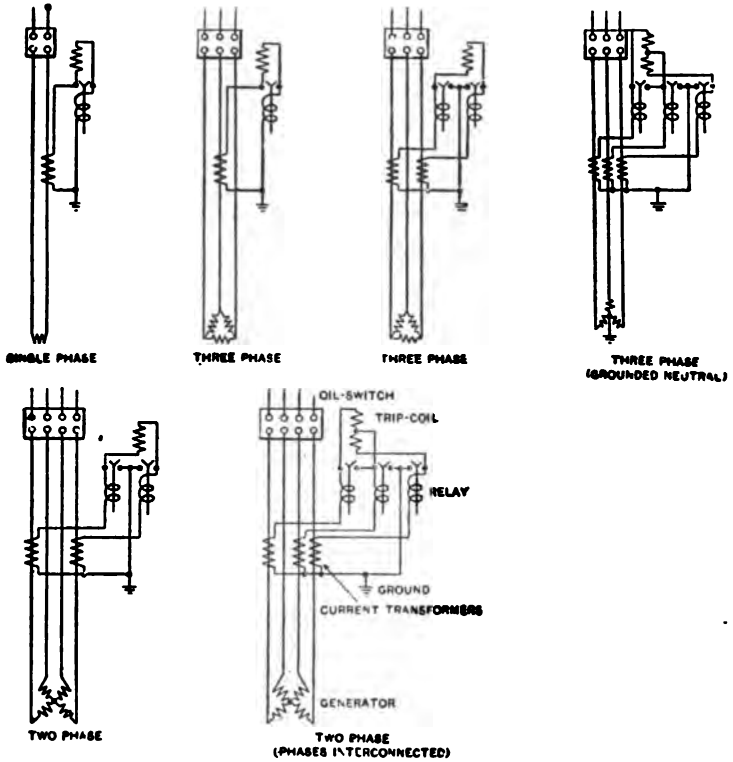


FIG. 118.—Connections of Oil Switches with Trip Coils Operating from Series Transformers through Circuit Opening Relays.

transformers in the line, which is in turn dependent upon the number of phases of the system, upon the balanced condition of the load, and upon the kind of armature winding connections (with or without grounded neutral), as has already been mentioned under Fig. 84. Fig. 118 is the same as the corresponding diagram of Fig. 84, with the exception of the relay installation, which under normal conditions keeps the secondary transformer winding short-circuited, opening the short-circuit only at overload when it excites the trip coil.

Figs. 117 and 118 show the switching arrangements of automatic oil switches operated manually.

Polyphase maximum relays operated by the current in two or three of the phases should, however, be used as seldom as possible and instead single-phase relays connected entirely separately in two or three of the phases on three or four wire system respectively should be used. With the former very large dangerous overloads can continue to exist in any one phase without causing the relay to operate and open the circuit. The same objections apply to polyphase reverse current relays.

One of the wrong connections often met is that where the so-called "resultant scheme" of relay connection is in use, namely: One single-phase relay connected to two series transformers so that current in the relay is the vectorial resultant of the current in each of the phases in which the series transformers are situated, assuming a three-wire three-phase system. Assume the normal full load secondary current of the transformer to be 10 amp. and that the relay be set to operate at 200 per cent. of full load current, that is, it will operate at 34.6 amp. If overload should occur on both phases connected through the transformers to the relays and the phase displacement in each phase is the same, then the circuit is opened when there is 20 amp. secondary current in each phase. Should, however, an overload occur in one of the phases the phase displacement will probably not be the same in each phase. If the angle of lag in each phase is equal and only one of them is overloaded, it will require 282 per cent. full load current in the single overloaded phase to cause operation of the switch. Should the current in the single overloaded phase lag 60° more than the other phase, then the current in this overloaded phase must increase to 386 per cent. of full load current before the relay actuates the switch. The protection therefore is quite uncertain. Similar conditions may occur in a four-wire three-phase system when three series transformers with only two single-phase relays are used. It is quite possible for one phase to be overloaded, since it has a large return path through the fourth wire. If this overload has a large phase displacement relative to the currents in other phases, then the condition may arise of very large overloads in the one phase and the switch not opening, consequently the same number of single-phase relays

as series transformers should be used, with four wires three transformers and three relays, and with three wires, two transformers and two relays.

The diagram for a relay with a solenoid-operated oil switch is given in Fig. 119. The two small auxiliary switches of Fig. 93 are replaced by a single one, which closes the *a* side when

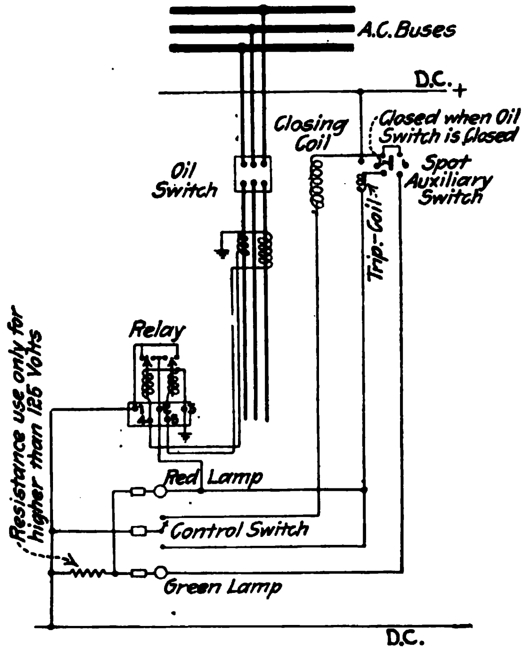


FIG. 119.—Connection of Controlling Circuit for Solenoid Operated Oil Switches.

the switch is closed and the *b* side when it is open. At overload the relay closes the d.c. circuit for the smaller solenoid, which opens the switch. A relay could also be inserted in Fig. 93 by connecting terminal 1 of the relay to any point between the red lamp terminals and switch 2, and terminal 2 of the relay to the negative side of the d.c. source.

Fig. 120 is a diagram for a single-pole relay with two electrically interlocked solenoid-operated oil switches. Fig. 121 shows the connections of a d.c. motor with a relay for the H3 and H4 oil switches. These switches are opened by a spring released by a trip coil, which is connected to the circuit by the

controlling switch on the board, or which may be excited automatically by the relay.

Fig. 122 shows a three-pole circuit-opening reverse-current relay which opens the short-circuited secondary winding of the series transformer at the moment of current reversal, and admits current to the trip coil. P_1, P_2, and P_3 are connected to the secondary windings of shunt transformers, C_1, C_2, and C_3

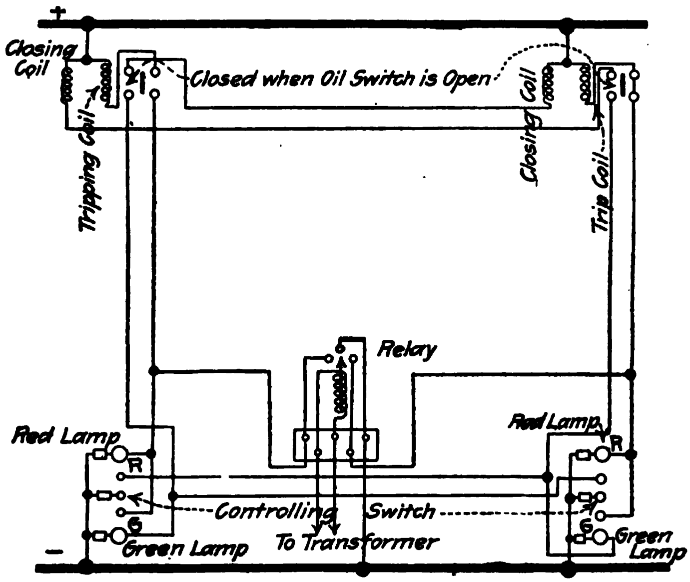


FIG. 120.—Connection of Two Interlocked Solenoid Operated Oil Switches.

to the secondary windings of series transformers and A_1 and A_2 to the trip coil. Fig. 123 is a wiring diagram for a double-pole circuit-closing reverse-current relay with a separate d.c. source for the trip coil. The connections of A, C, and P are the same as those in Fig. 122.

Mr. M. C. Ripinski in the *Electrical World* for November 2, 1907, gives the following diagram for the connection or relays for a three-phase system. Three generators with Y armature windings, and neutrals grounded through resistances, supply a set of busbars from which four feeders lead to the substations, each two feeders supplying one set of substation busbars. One set of busbars supplies a low-tension set of busbars, through step-down transformers, which in turn supply a.c.

feeders. The current from the other busbar set feeds converters through transformer sets which deliver d.c. for power distribution. See Fig. 124.

Overload, reverse power inverse time-limit relays operate at the moment of overload or short-circuit for the normal direction of energy flow. In case of reversal of energy in a feeder

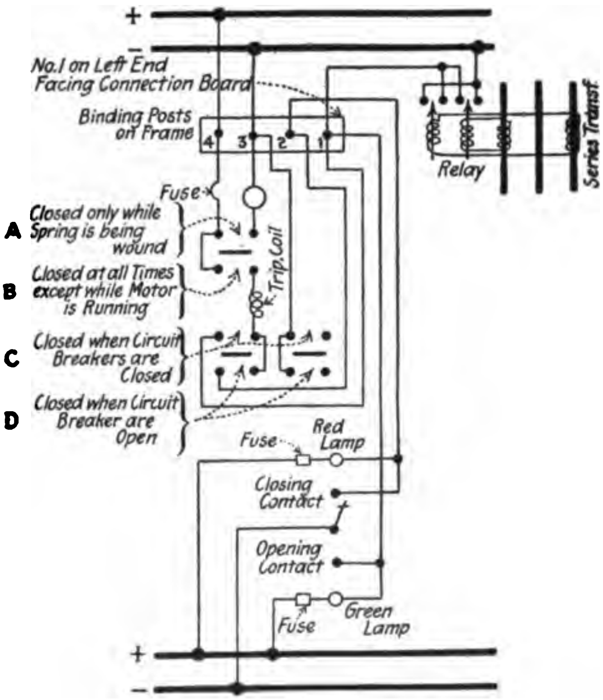


FIG. 121 —Internal Wiring for Motor Operated Switch Mechanism.

this relay operates as a reverse-current relay for a current strength from one-third to one-eighth of the overload current for which it is set. Let us consider three feeders leading from central station A to substation B. (See Fig. 125.) In case of short-circuit at point X, there will be more current through switch D than through E or F, because the short-circuit is nearest to D. Therefore, the overload current will open this switch by means of its overload relay. At the same instant, however, there is a rush of current from the substation towards X, which operates the reverse-current relay P, and opens its

corresponding switch. In Q and R, and also in E and F, very large currents exist in the normal direction, but D and P are opened more quickly because of the still greater current through D, and the action of the reverse current through P, which suffices to open P at one-third the value of the overload current. This action relieves the other relays quickly enough to prevent their being opened. In this case the devices act as inverse time-limit relays.

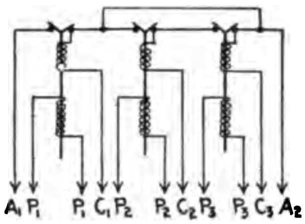


FIG. 122.—Three-Pole Circuit Opening Relay.

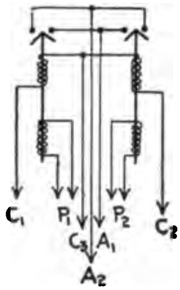


FIG. 123.—Two-Pole Circuit Closing Relay.

Another illustration is that described by Mr. George F. Chellis in his paper on time-limit relays referred to above. In Fig. 126 we have a three-phase generator supplying energy to four outgoing feeders which feed four synchronous converters in the substation. In the substation the a.c. busbars are equipped with bus-sectionalizing switches, so that eventually the machines and feeders can be worked as independent units. The generator oil switch is automatic and is operated by means of a differential relay. "Should a short-circuit occur at the point X on the B feeder there would be a rush of current from the power house busbar, and also from the substation busbar to the point X. In A, C, and D the current would be increased, due to the short-circuit being fed by these feeders through the substation busbar. Since a synchronous converter generates an a.c. electromotive force corresponding to rated pressure at synchronous speed, in case the point X is near the power house, it is possible that the direction of the flow of energy in feeders A, C, and D would be reversed due to the synchronous converters feeding the short-circuit back to the power house busbar as well as directly over the short-circuited feeder."

For this reason the switches on the substation side of the feeders should be protected by an instantaneous reverse-current relay, while the power house should be guarded by an overload time-limit relay. Since, as has already been mentioned, the

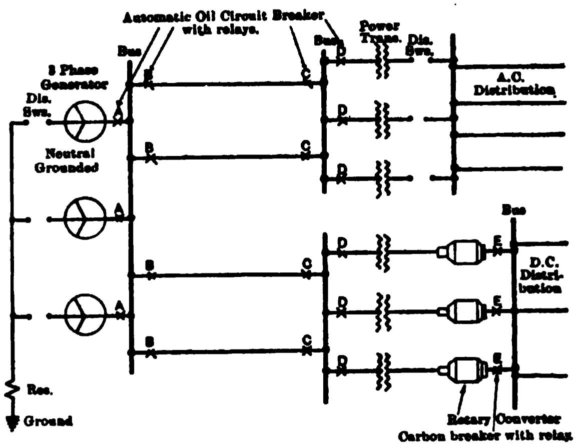


FIG. 124.—Relays in a Four-Wire Three-Phase System.
A and C, alternating current overload reverse power inverse time-limit relays.
B and D, alternating current overload inverse time-limit relays.
E, direct current reverse power inverse time-limit relays.

reverse-current relays are dependent upon the pressure of the system, they would become practically inoperative at zero or low pressure which exists at the moment of short-circuit. They therefore lose their reverse action and become worthless at the very instant when they are most necessary.

Since the relative value of the time element of relays is determined by the various conditions of service and load, it is

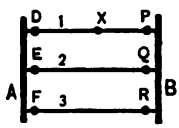


FIG. 125.—Connection of Relays for a Three-Phase System.

impossible to formulate any empirical rules applicable to all cases. The choice of the proper device is left to the judgment of the engineer, who must take into consideration the reliability of the various types available. In some instances the relays

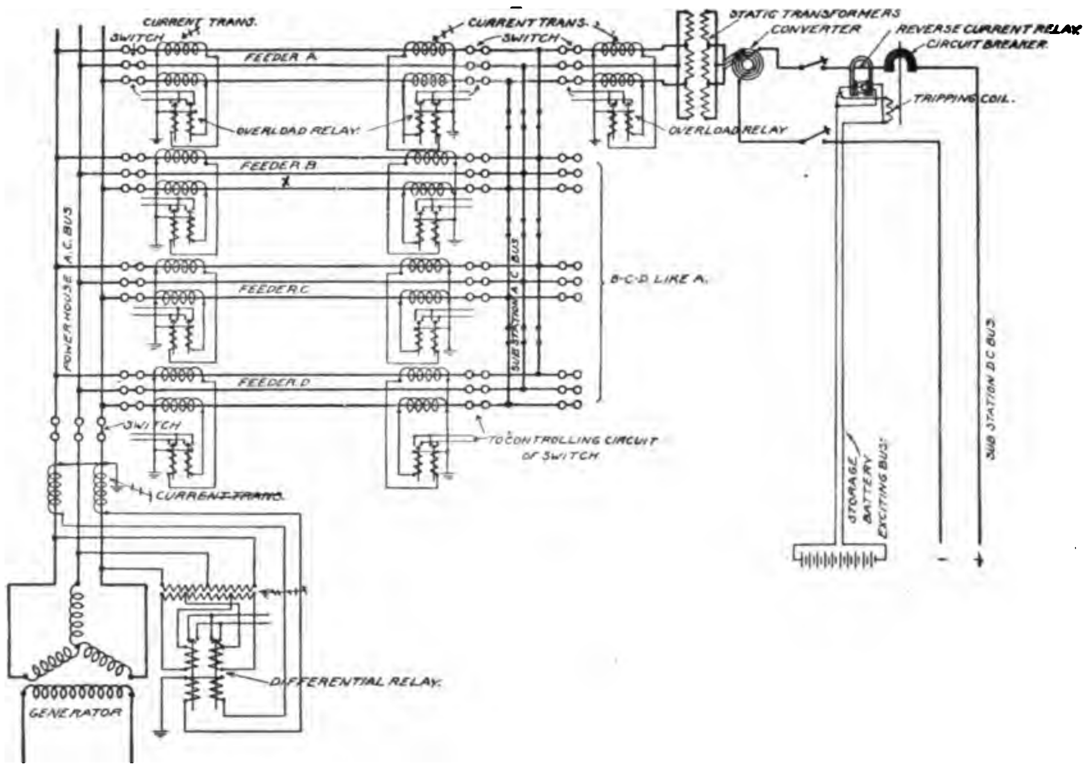


FIG. 126.—Typical Layout for Three-Phase System Showing Location of Relays.

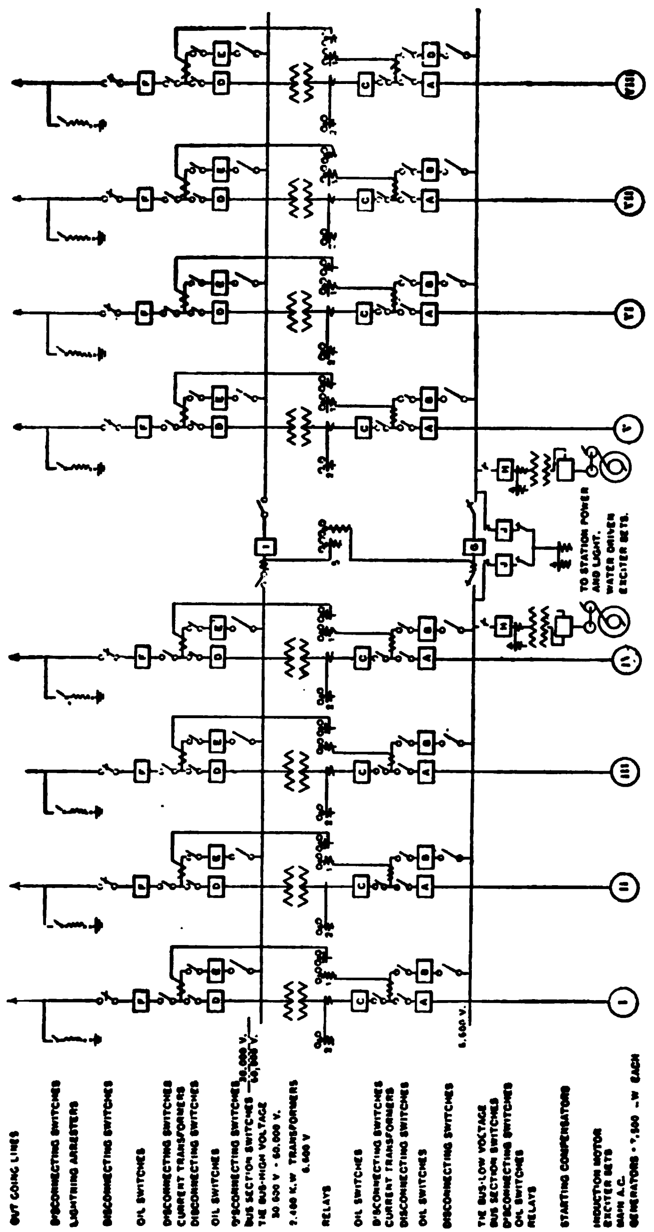


FIG. 128.—Typical System of Connection for a Large Power House.

are used simply to operate tell-tales or signal lamps, by which the attention of the operator is called to the action of the corresponding switches or other apparatus.

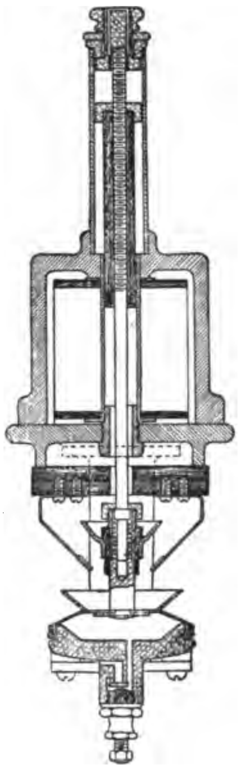


Fig. 127.—Time-Limit Overload Relay.

A relay consists of a mechanism operated by a solenoid which is excited directly or indirectly by the current of the line to be guarded. The mechanism carries a set of contacts which open or close a corresponding set of fixed contacts as the case may be. A relay adjusted to a certain time element possesses a special mechanism to accomplish this adjustment. The exciting mechanism generally consists of a solenoid with a core, while in other cases it is a movable armature winding similar to that on a motor, or it may be constructed as a wattmeter. Still others are operated by clockwork. There are two pairs of metal contacts, one movable and the other fixed. The fixed contacts are either in shunt with the operating current, being closed under normal conditions, as in the case with an a.c. excited trip coil, or they are in series with the operating current, being open under normal conditions, as is the case with a trip coil excited from an independent d.c. source. The fixed contacts are bridged by the movable set.

Fig. 127 is a section through a single-pole time-limit overload circuit-closing relay, as made by the General Electric Company. The bellows on top are used to adjust the time element, by regulating with small set-screws the air passage from the bellows through a small channel, at the moment of the upward motion of the solenoid core. By combining two or three single-pole relays we may obtain a double or triple-pole apparatus. Instantaneous relays are similarly constructed with omission of the bellows. An arrangement of oil switches with various types of relays for a large power station is given in Fig. 128.

CHAPTER XVII

POTENTIAL REGULATORS

A POTENTIAL regulator is a device intended to maintain a constant e.m.f. of the generators or feeders, independently of load and without disturbing the e.m.f. of other parts of the system. Two kinds of regulators are to be distinguished, the Tirrill regulators which maintain a constant e.m.f. of the generators, and the feeder regulators which maintain a constant feeder e.m.f.

TIRRILL REGULATORS

This apparatus regulates the e.m.f. of the generator by varying the field strength with the load. There are two types, of which the first regulates the voltage of shunt and compound-wound machines, while the second regulates the pressure of machines requiring a separate exciter, the latter being applicable to both d.c. and a.c. machines. Fig. 129 shows the elementary connections of a regulator (type T. D.), for a compound-wound machine. The regulation is accomplished by automatically throwing the field rheostat on or off the circuit. This eliminates the variations in the machine voltage due to variations in load by decreasing or increasing the field strength. The mechanism consists of a main control magnet energized by current from the main busbars, or from the center of distribution. In the first case it is desired to regulate the voltage on the busbars, while in the second case such regulation depends upon a given value of the pressure at the load center, whence we have direct or indirect voltage regulation. The magnet actuates a lever carrying a contact stud at its free end, opposite to a fixed contact. A spring opposes the action of the magnet which is adjusted so that at the required voltage the lever will vibrate under the action of both magnet and spring. This vibration of the lever opens and closes the main contacts, which causes an opening and closing of a pair of relay con-

tacts, of a differential relay. The relay consists of two equivalent windings, wound opposed to each other, both being in shunt with the main current, but one being energized permanently, and the other only at the closing of the main contacts. When the main contacts are open, there is current through only one of the relay windings, the relay is magnetized, attracts an armature, and opens the relay contacts. With the closing of the main contacts, there is also current through the second relay winding, and since the windings are opposed

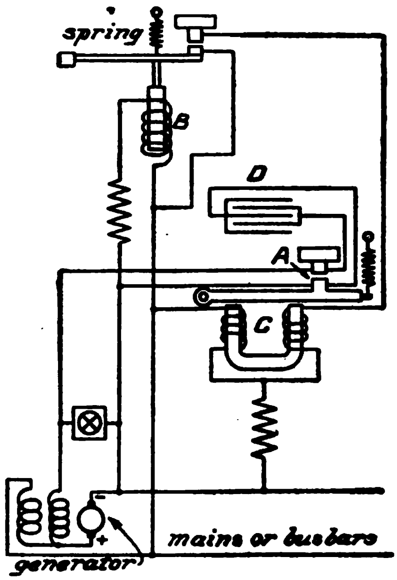


FIG. 129.—Diagram of Connection of a Tirrill Regulator for Direct Current.

to each other the relay becomes demagnetized and the armature closes the contacts under action of the spring. The effect of opening and closing of the relay contacts causes the field rheostat to be thrown on or off, the time element of action for either closing or opening being dependent from the momentary fall or rise of the pressure on the busbar or feeder as the case may be. In order to prevent arcing between the contacts, these are connected to a condenser set.

Fig. 130 is a wiring diagram for a Tirrill regulator connected to two generators in parallel, which supply a three-feeder sys-

tem. The size of the control resistance in the magnetic circuit is varied according to the required voltage. If a 125-volt generator, for instance, is to generate 110 volts, binding post No. 14 on the resistance box is joined to binding post No. 1 on the regulator. Tables made for each regulator give the binding posts to be used for the required voltage. An adjustment of the spring opposing the magnet must be made for the required voltage, so that when this pressure is reached the main contacts will vibrate properly. If the voltage at the load center or busbar drops, due to increase in load, the spring overcomes the magnetic pull and closes the main contacts, which results in

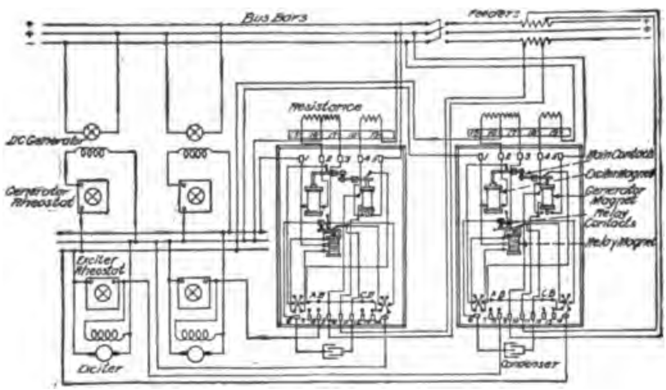


FIG. 180.—Connection of Tirrill Regulators for Three-Wire System for Direct Current.

demagnetizing the relay and closing the relay contacts that short-circuit the field resistance. The voltage is then allowed to rise until normal conditions again prevail. These fluctuations are quite rapid, so that as a matter of fact the voltage is kept at a constant value.

Tirrill regulator (type T. A.), for regulating the voltage of separately excited machines, is similar in operation to type T. D. in that it regulates the impressed exciter voltage with fluctuations of the load. The variation of the exciter current is made with constant field resistance by short-circuiting the a.c. field rheostat, so that the impressed exciter voltage is at all times the same as the voltage across the terminals of the exciter itself. The regulator therefore influences the generator field indirectly, and the shunt field of the exciter directly, the last

similar to the action of type T. D. on the generator field. A further similarity between this type and type T. D. is that it throws the shunt rheostat of the exciter on or off, by means of a main control magnet, main contacts, differential relay, and relay contacts. The two types differ in that the second main contact piece, instead of being fixed as before, is fastened in the T. A. type to a lever actuated from a.c. solenoid core. Two windings, one a potential and the other a current winding, make up the a.c. magnet, which receives current from transformers joined to the busbars or feeders. See Fig. 131. With d.c. generators the transformers are of course omitted, the

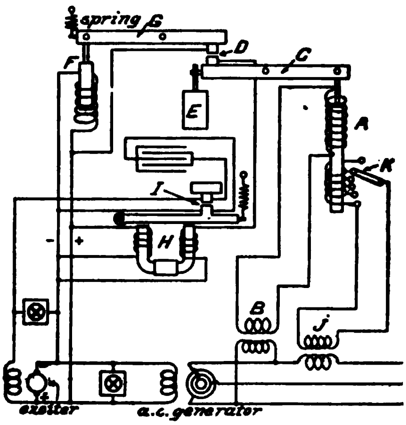


FIG. 131.—Diagram of Connection of a Tirrill Regulator for Alternating Current.

potential windings being connected directly to the busbars or load center, while the current winding is joined to the line through a resistance. Current is supplied to the main magnet by the exciter, and the magnet works on a lever on whose further arm one of the main contacts is fixed. Four springs, fastened to different points of the lever on the side of the main contact, oppose the action of the magnet. They come into action consecutively according to the position of the lever, that is, according to the value of the exciter voltage.

The adjustment and action of the springs and magnet is such that the rise of the contact piece is directly proportional to the change in the exciter voltage. Since the latter is in fact a fluctuating e.m.f. due to the variation of load on the gen-

erator, the lever with the main contact is set vibrating under this influence. The maximum amplitude of vibration is 1-16 inch. The position of the upper contact is, therefore, determined by the exciter voltage. The winding of the a.c. magnet is supplied with a current whose value is at all times proportional to the generator voltage. The solenoid pulls the laminated core upward. This core is attached to a lever on whose outer arm a counter-weight is applied, and the second stud of the main contact pair is also fastened on this end. The motion of the core is damped by an oil brake.

For a given generator voltage the position of the second contact is determined by the position of the core in the solenoid and the size of the counter weight. Since a different electromotive force is applied for each different position of the core in the solenoid, under the same generator voltage, a position of the core is chosen which will call the maximum electromotive force into action at the moment when the contacts are closed. The upper contact is kept in position by the exciter voltage which corresponds under normal conditions to the required generator voltage. The counterweight is so chosen that it will exactly balance the weight of the core and the electromagnetic pull on the core at the moment the contacts are closed. The sum of the moments acting on the lever must be zero for the required generator voltage, so that the system is in equilibrium. As soon as the lever is changed from this position, the electromagnetic pull acting on the core is changed. It, in fact, becomes less, so that the moment due to the weight of the core predominates in all other positions of the core. The lever, therefore, is in unstable equilibrium for the voltage in question. If the load on the generator is changed from zero to maximum, and the exciter voltage varies at the same time from minimum to maximum, the upper contact is shifted about 1-16 inch. Since the solenoid lever remains in contact with the upper stud, and since the shifting of this stud is very slight, the lever may still be considered to be in equilibrium as long as the generator voltage remains constant. Should the generator voltage drop, the moment due to the weight of the core predominates, producing clockwise motion. If the generator voltage rises above normal value, the magnetic pull increases and the lever is under the influence of a counter-clockwise

moment. It must be borne in mind that the solenoid lever was adjusted to maintain equilibrium for a given generator voltage.

The following example may serve to illustrate the action of the complete apparatus. Let it be assumed that the constant voltage of the system, as expressed in the voltage of the secondaries of the potential transformer is 110 volts, and that the load and speed of the generator are constant, so that the vibration of the contacts is uniform. The core of the solenoid is set for the given voltage. Let us start with the time element during which the exciter field rheostat is short-circuited, as represented by Δt_1 in Fig. 132, that is, when the main contacts, and hence the relay contacts, are closed. During this interval the current D of the shunt-field winding of the exciter rises,

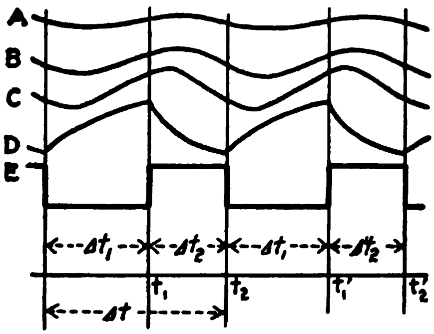


FIG. 132.—Curves Showing Performance of a Tirrill Regulator.

causing the exciter voltage C to increase, which in turn increases the exciter current B and the effective generator voltage A. The values are changed, but are displaced in phase on account of self-inductance. The upper contact moves upward on account of the rise in exciter voltage. As long as the generator voltage remains below 110 volts the solenoid lever is subjected to a clockwise movement, causing the lower contact to rise also, and press against the upper one. When the generator voltage reaches 110 volts or more, the solenoid lever commences to turn in an opposite direction, therefore opening the main contacts. This occurs at the point t_1, so that the exciter field rheostat is again thrown in. The upper contact continues to rise under the growing exciter voltage until the influence of the exciter field rheostat, now in circuit, becomes noticeable. The exciter

voltage begins to fall off, and the upper contact reverses its movement. During this time the generator voltage continues to rise above 110 volts. The lower contact is lowered until the generator voltage reaches a maximum value and commences to fall under the influence of the falling exciter voltage. When this falling voltage reaches 110 volts and less, the motion of the solenoid lever is reversed, causing the lower contact to rise. The two contacts approach each other until they meet at the point t_2, when the exciter field resistance is short-circuited. The tendency of the contacts to continue their motion is counteracted by a flat spring to which the upper contact is attached. The spring is bent, and both contacts follow the same constrained path until they are again separated. The motion of the mechanism remains constant as long as the load and speed of the generator remain unvaried. All of these motions are very rapid. The larger the maximum resistance of the exciter field circuit on throwing in the field rheostat and the smaller its minimum resistance on short-circuiting the field rheostat, the more rapid will be the motions. The more rapid are the fluctuations in the generator field and in the magnetic pull on the solenoid core, the more rapid will be the motion of the mechanism and the opening and closing of the contacts. The greater the frequency of the contact vibration, the less the time allowed for changes in the exciter excitation, however, the less will become the fluctuations of the exciter and generator voltages. And finally, the greater the frequency of the generator excitation, the more rapidly will the voltage fluctuations due to the load variations, be removed. These conditions, therefore, call for as high a maximum resistance and as low a minimum resistance as possible in the exciter field. The minimum resistance is kept to a low value by short-circuiting the a.c. field rheostat. The maximum resistance, on the other hand, is obtained by setting the exciter field rheostat to a value, which, when permanently connected to the exciter, will reduce the generator voltage to from 40 to 65 per cent. of its normal value. Any change in the load or speed of the generator will result in a disturbance of the uniformity of the contact vibration, which will last as long as the voltage fluctuation continues. For instance, under rise of load and fall of voltage, the solenoid lever moves in a clockwise direc-

tion, which closes the main contacts and short-circuits the exciter field rheostat. It is seen therefore that the regulator brings about an immediate rise in the exciter voltage so that its generator voltage reaches its normal value in the shortest possible time. As soon as the e.m.f. rises above 110 volts the contacts are opened and the normal vibration commences. The voltage fluctuation under normal conditions is so rapid and so

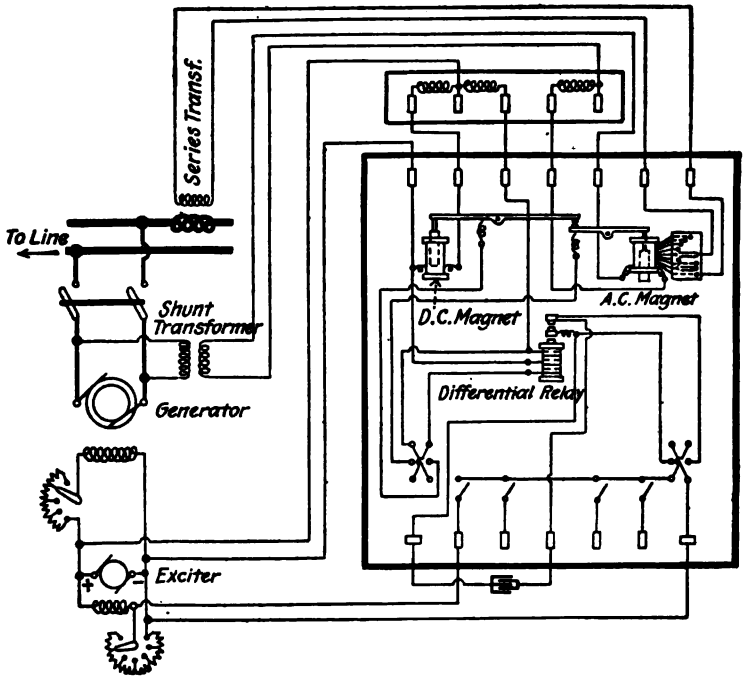


Fig. 133.—Connection of Tirrill Regulator with One Alternator.

small that the normal voltage of 110 may be considered practically constant.

Fig. 133 shows a diagram for connecting a T. A. regulator to a generator, the voltage of the busbars being kept constant.

If the generator voltage is to be increased by a certain amount, although the solenoid lever is set for 110 volts, the series coils of the solenoid may be connected in series with the potential coils, so that the two windings are opposed to each other. This does away with the series transformer. Both

windings are excited by the same current which before supplied the potential coils alone, with the result that the effective electromagnetic pull becomes less by an amount corresponding to the decrease in the number of effective ampere-turns. The decrease depends upon the number of series turns opposing shunt turns. The action of the decreased magnetic pull on the

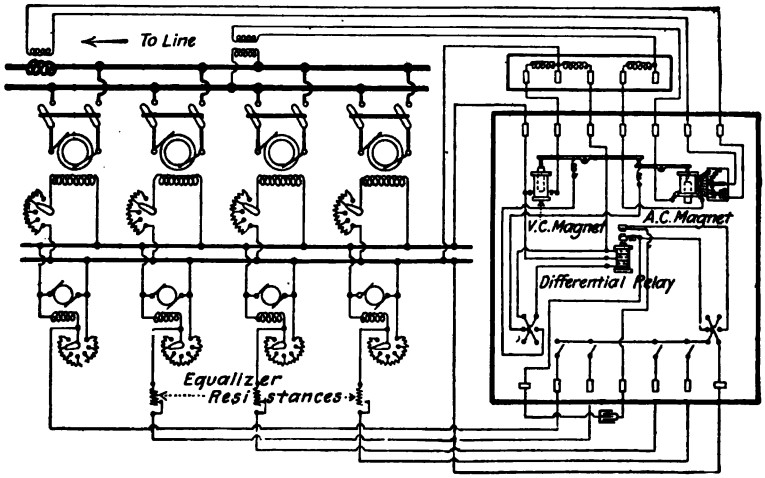


Fig. 134.—Connection of Tirrill Regulator with Four Alternators in Multiple.

core and lever is the same as would be that of a decreased generator voltage. The result is an increase in this voltage of as great a percentage as the percentage decrease in the effective windings of the solenoid.

If the voltage of the system or of a single feeder is to be kept constant, the current winding is joined to the secondary of a series transformer connected to the feeder in question. When the generators are in parallel, and are excited by the same exciter, their voltage can be kept constant by a regulator joined to the exciter busbar, and also through transformers to the main bus.

Fig. 134 shows a system of connections for a regulator with several generators and exciters. All of the control rheostats are connected in parallel with the relay contacts and are short-circuited simultaneously. Any one of the exciters can be disconnected from the regulator at will. Resistances are intro-

duced into the regulator leads in order to prevent equalizing currents. If it is not desired to connect the exciters in parallel, but that each exciter work directly on the field of its generator, then the field-windings of the exciters are connected in parallel with each other, and also in series with a common resistance, which is influenced by a Tirrill regulator. (See Fig. 135.) Only

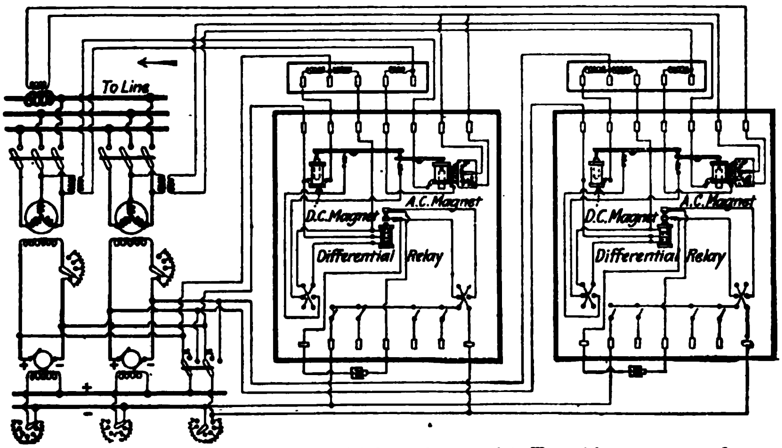


FIG. 135.—Connection of Terrill Regulator with Two Alternators and Separate Exciters.

one of the two regulators is in use at any given time, the other serving as a reserve.

For exciters with greater shunt-field currents, Tirrill regulators are used with a number of relays and corresponding switches, to avoid sparking at the relay contacts.

FEEDER REGULATORS

One of the most important considerations in an a.c. lighting system is to keep the voltage in the main feeders constant. Since these feeders are subjected to a constantly varying load, an efficient regulation of the individual feeders gives an effective regulation of the entire system. The use of feeder regulators is of particular value for incandescent lighting systems, where it is essential that all the lamps should burn with equal brilliancy. When the generator supplies only a single circuit, the line voltage can be kept constant by regulating the generator voltage for the given line loss. This would be impossible where

there are a number of circuits to deal with, unless all of the circuits have the same line loss. Under such conditions the best that can be done is to regulate the generator pressure for the average line drop, so that the pressure in some of the feeders will be higher than in others. An independent voltage regulation of the circuits is made possible, however, by inserting feeder regulators in each feeder.

The action of the feeder regulator is similar to that of a transformer, or rather compensator with two distinct windings. The primary is connected in shunt and the secondary in series with the feeder to be controlled. The product of the voltage and current on the busbar side is equal to the corresponding product on the feeder side of the regulator, with a slight correction due to the loss in the feeder. Fig. 136 shows two diagrams of connections for boosting and reducing

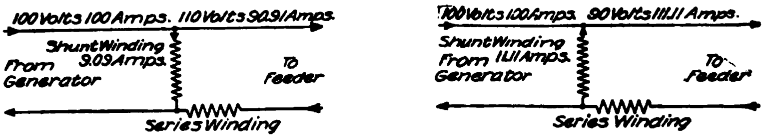


FIG. 136.—Boosting and Lowering by a Potential Regulator.

the feeder pressure for a single-phase line, given a 100-volt, 100-ampere circuit, and a regulator whose range is 20 per cent., that is 10 per cent. boosting and 10 per cent. reducing, neglecting the losses in the regulator itself. With a rise of feeder voltage a part of the current goes back to the line through the primary winding, and this amount is deducted from the useful current in the feeder, while an increase of current results from a drop of pressure. It is important to distinguish between regulators and control resistances or reactances. The latter reduce the voltage by absorbing it. For since their windings are in series with the line, the current at both ends must be the same, so that there is a loss in voltage. The product of amperes by the difference in pressure across the ends of the winding represents a loss, and since the regulation of the current in the feeder is made to depend on this loss the result is a low efficiency.

Feeder regulators may be divided into switch or control

regulators and induction regulators, the latter being single or polyphase. They are all subject to manual or automatic operation.

SWITCH OR CONTROL REGULATORS

A switch or control regulator is a transformer with both windings on the same core. The primary winding is connected across the feeder, and the secondary is in series with it. The

FIG. 137.—Dial Switch Feeder Regulator.

secondary can be gradually thrown on or off the line by a dial switch, upon which fact the operation of this type of regulator is based. Fig. 137 shows the external casing, and Fig. 138 shows the internal connections of a type C. R. regulator. (G. E. Co.) In the position of maximum boost the dial switch is in the extreme left-hand position, where all secondary windings are thrown into circuit. By turning the switch from left to

right the windings are thrown out, one by one, until they are all short-circuited in the extreme right-hand position. At this point the line voltage is the same as that on the generator side. With a continued motion of the switch in the same clockwise direction, a reversing switch is automatically thrown, causing the dial switch to cut the secondary winding in again step by step, and so lower the generator voltage. Two complete rotations of the dial switch are therefore possible, one for boosting, and the other for lowering the feeder pressure. At the positions of maximum or minimum voltage the direction of rotation must be reversed. In the extreme positions the switch is automatically arrested to prevent it from turning too far in the same direction. The change in feeder voltage is therefore made step by step. The precision of regulation depends upon the number of contacts or taps on the secondary. Great precaution

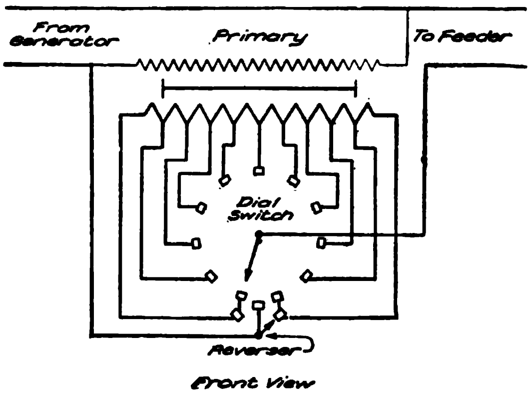


FIG. 138.—Internal Connection of Dial Switch Feeder Regulator.

is necessary in breaking the circuit, while the dial switch is moving from one contact to another, as adjacent coils must not be short-circuited. The regulator may also be driven by a motor, being controlled from the switchboard by a small reversing switch. This type is air-cooled.

Another form of switch regulator is given in Figs. 139 and 140. This is an oil-cooled transformer with both windings on one core. The coils are suspended from the cover. The switch resembles a controller in form. The device consists of a stationary drum on which are fastened the contacts for the

various coils of the secondary winding. Inside the stationary drum is a second one on which is mounted a row of collector rings insulated from each other. A set of metallic fingers of

Fig. 139.—Controlling Mechanism of Controller Type Regulator.

different lengths make permanent contact with the collector rings so that when the vertical axis of the regulator is rotated, the fingers move on the upper faces of the contact pieces. The rings are connected in parallel through protective resistances and are joined in series with one end of the feeder. The other

end of the same feeder is permanently connected to the middle point of the secondary. Regulation is accomplished by connecting the finger switch to a rotating flywheel by a horizontal bevel gear and two vertical pinions. A magnetic clutch keys one or the other of the pinions to the flywheel shaft, on which they run loose, according as boosting or depressing is required of the regulator. The flywheel is actuated from a rotat-

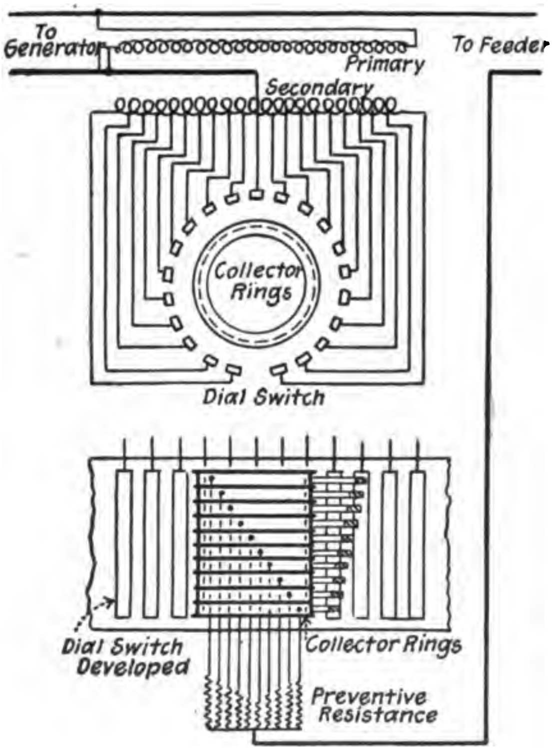


FIG. 140.—Internal Connection of Controller Type Regulator.

ing shaft which generally serves for operating a series of regulators. The magnetic clutch excitation is controlled by a contact-making voltmeter, quite similar to the a.c. solenoid and lever discussed under Tirrill regulator type T. A.

Fig. 141 shows the connections of the contact-making voltmeter. The apparatus consists of a solenoid whose core actuates a lever. A spring at the farther end of the lever op-

poses the magnetic pull of the core. The lever is connected with one side of the d.c. source of energy (see Fig. 142), and vibrates between two contacts which are connected to the armatures of the magnetic clutches. A potential and a current winding, fed by shunt and series transformers in the feeder to be controlled, make up the solenoid. The current windings can be partly cut in or out by a dial switch, thus limiting the regulation to a fixed value. The direction of motion of the lever

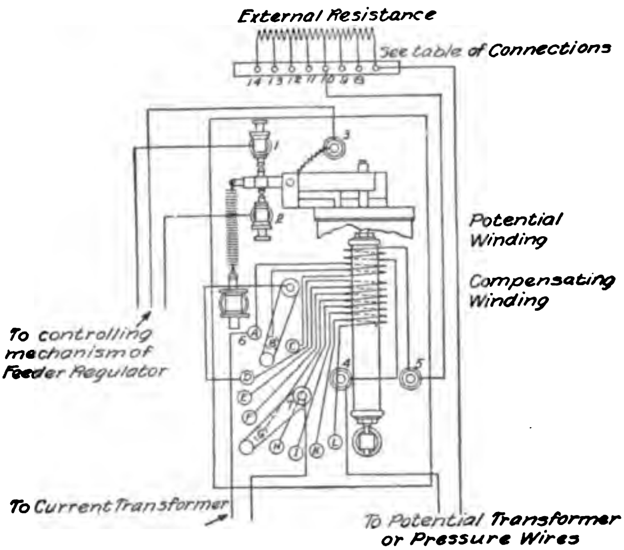


FIG. 141.—Connections of Contact-Making Voltmeter.

determines which of the two magnetic clutches is to be excited and therefore controls the direction of rotation of the horizontal bevel gear. A limit switch opens the circuit for the magnet in the extreme position of the finger switch of the regulator.

The efficiency of this regulator is very high, reaching almost 100 per cent. Since the motion is imparted to the small finger switch the moment of inertia and turning moments of the movable parts are small, so that the time element of the apparatus is very short. Moreover, quite precise regulation is obtainable because of the large number of contacts. Switch regulators are used for single-phase leads rated at less than 200

amp. at 2200 volts, 60 cycles, and with regulating range of 10 per cent. either way, making a total of 20 per cent.

The Westinghouse dial type "step by step" regulator is built on the same principles as the General Electric device just described. The only difference is that with the former type the dial switch is mounted on the board away from the transformer to which it belongs, and the individual taps of the transformer secondary are joined by leads to the contact studs of the switch. These dial switches can be used directly for cur-

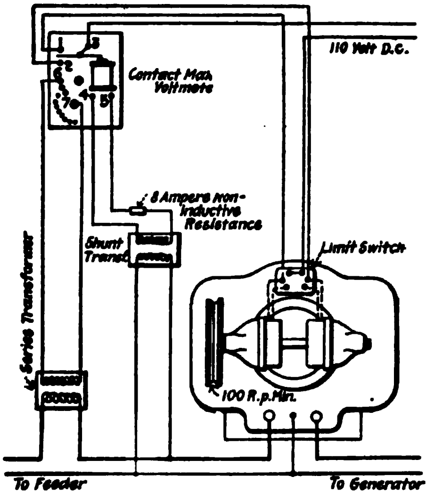


FIG. 142.—External Connection of Controller Type Regulator.

rents of 100 or 200 amp. For larger values a series transformer is used, in addition to the regulator transformer. They can also be used for service voltages up to 2500, and for voltages from 3300 to 6600 they are employed in connection with series transformers. The primaries of the regulator transformer are shunted across the line, while the secondary taps lead to the dial switch. The secondaries of the series transformers are in series with the line, and two leads from the primaries are connected to the dial switch.

The Westinghouse drum type "step by step" potential regulator likewise consists of a separate control switch and a regulator transformer. The controller is similar to the kind

used for electric street railway service. It consists of a cast-iron top and base held together by steel bars. Two of the bars carry the insulated contacts of the controller to which the transformer leads are connected. Inside the casing there are two revolving drums with their respective sets of fingers, one of which accomplishes the switching on or off of the transformer secondaries, while the other serves to reverse the regulation; i. e., according as a boosting or lowering of the voltage is called for. A so-called "floating coil" is used for the large

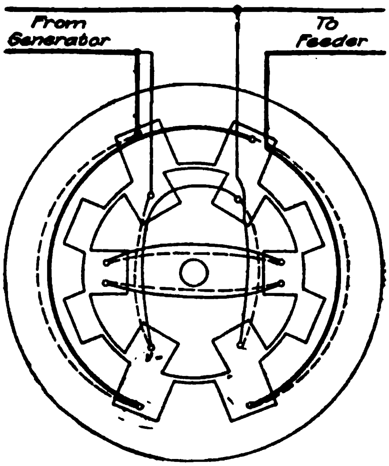


FIG. 143.—Arrangement of Primary (Armature) and Secondary (Field) Cores and Windings in Single-Phase Feeder Induction Regulator. Armature in Maximum Lowering Position.

number of steps of this regulator. It is simply an independent part of the secondary winding having a large number of well insulated taps. These taps and the whole floating coil can be connected with the rest of the secondary winding in a great many different ways. Precise regulation of the voltage is therefore possible with a maximum degree of freedom from arcing when cutting the windings in and out.

INDUCTION REGULATORS

The operation of these regulators is based upon a principle of regulation somewhat different from those discussed till now. The primary and secondary windings are respectively shunted

across and in series with the main line as before, but they are wound on separate cores. The secondary is wound on the inner surface of a stationary core, while the primary is wound on the outside of a movable core. Both windings are polar windings, and are so mounted that a given pole of one winding lies opposite to the same pole of the other. The regulation depends upon the displacement of one of the poles relative to the stationary pole. As long as two similar poles lie opposite each other the regulation is at maximum boost, but as soon as they become displaced, so that dissimilar poles are adjacent, the

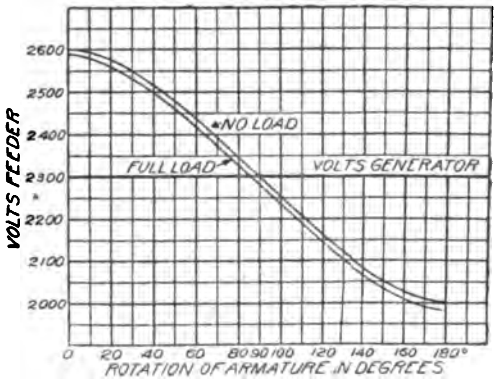


FIG. 144.—Curves Showing Boosting and Lowering of Feeder Voltage by Induction Regulator.

regulation drops until it reaches its lower value. The regulation with this type of apparatus is gradual. Two types of induction regulators may be distinguished, namely single-phase and polyphase.

SINGLE-PHASE INDUCTION REGULATORS

Fig. 143 shows the arrangements of primary and secondary cores and windings in single-phase induction feeder regulators. The primary flux and consequently the flux through the secondary coils has a constant direction with respect to the movable core, namely perpendicular to the plane of the primary winding. As the core is rotated gradually the relative direction of the primary flux to the fixed secondary winding is varied and produces a gradually varying e.m.f. in the secondary, from the maximum positive, through zero, to the maximum negative

value. In the position where the direction of the primary flux is opposed to the secondary flux, the voltage generated by the primary in the secondary is added directly to the line voltage, but is subtracted when the direction of the flux is the same. In any intermediate position of the primary winding, the primary flux, and consequently the flux in the secondary coils, is proportional to the angular position of the core. The generated e.m.f.

FIG. 145.—Single-Phase Induction Regulator.

is, however, always in phase with the excitation, and is therefore added directly to or subtracted directly from the line voltage. As shown in Fig. 143, the rotary core contains a short-circuited winding arranged at right angles to the shunt windings. Its object is as follows: In the positions of maximum boost or lowering, the primary flux neutralizes that of the secondary, for the fluxes are then in the same or opposite directions. With the armature in the neutral or no-boost, no-lower position the flux produced by the current in the secondary passes equally on either side of the primary coils, which can

not therefore neutralize the flux due to the secondary. The secondary flux sets up a self-inductance in the windings which reaches its maximum with the neutral position of the primary coils. This self-inductance of the secondary, if the line current is constant, requires a gradually increasing e.m.f. to maintain the current through the series windings. The voltage so

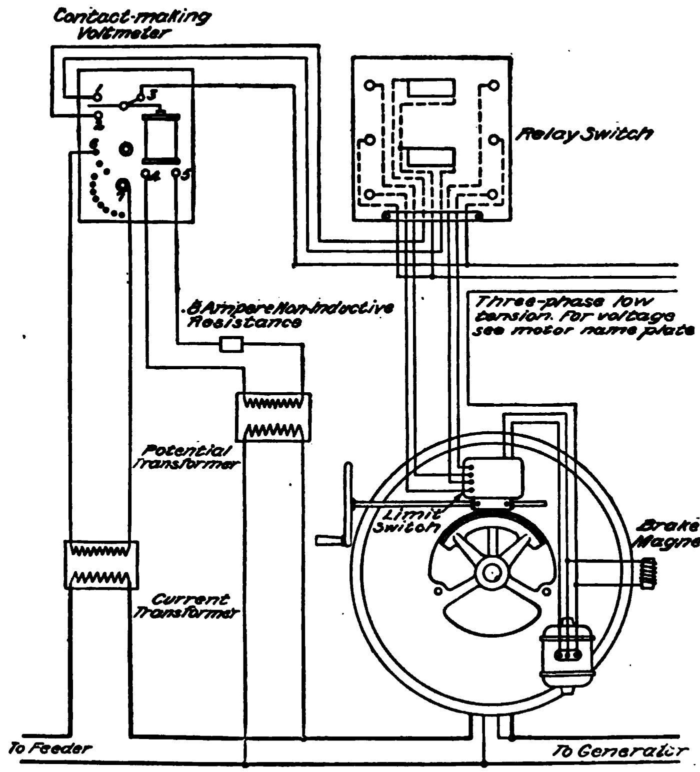


FIG. 146.—Connection of Automatically Operated Single-Phase Induction Regulators.

absorbed would be at right angles to the line voltage, and the result would be a poor power-factor in the feeder. The short-circuited coil on the armature, however, which is in direct inductive relation to the series coils when the armature is in the neutral position, acts as a short-circuit on the secondary winding, and therefore reduces the voltage necessary to force full load current through this winding to only a trifle more than

that represented by the resistance drop across the secondary and short-circuited windings. This short-circuiting of the secondary is gradual from zero in the maximum boosting position of the regulator to the maximum short-circuiting in the neutral position, so that by the combined effect of the primary and short-circuited coils the reactance of the secondary is kept within reasonable limits. The total ampere-turns of the primary plus the ampere-turns of the short-circuited windings are always approximately equal to the ampere-turns of the secondary. Fig. 144 is a graphical representation of boosting and lowering of feeder voltage by induction at no load and full load. The exterior of the regulator is shown in Fig. 145. The device is operated either directly by hand, or by chain and sprocket, by hand-controlled motor, or automatically. If automatically operated, the actuating motor should be of the polyphase type. The motor is controlled by means of a small double-pole double-throw switch which is automatically thrown

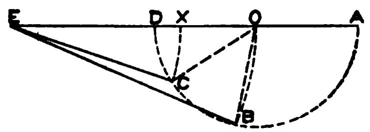


FIG. 147.—Change of Phase Relation in Polyphase Induction Regulator.

in by a small magnet, energized through a contact-making voltmeter.

Fig. 146 shows connections for an automatically operated single-phase induction regulator. The action of the contact-making voltmeter is similar to that described under Fig. 142. The up-and-down motion of the armature controls the excitation of the two coils of the relay switch magnet, and the regulator is operated by the motor in either direction.

POLYPHASE INDUCTION REGULATORS

The general construction of polyphase induction regulators is similar to that of the single-phase type of apparatus. The primary shunt-windings for the different phases must be identical in every way and arranged so that the various windings magnetize a given pole of the regulator in the same direction. Both windings are wound on their cores like the wind-

ings on an induction motor. With the polyphase type the field is not an alternating one as in the single-phase apparatus, but is rotary, and the speed of the rotation of the field per pole is the same as that of the generator. The value of the e.m.f. generated in the secondary is not changed by the motion of the primary coils, but the phase of both voltages is displaced, which changes the value of the load voltage which is the resultant of the two. In other words, both coils set up rotating magnetic fields in the same direction. The e.m.f. generated in the secondary is determined in value and phase by the value and phase of the resultant field. Since the absolute values of

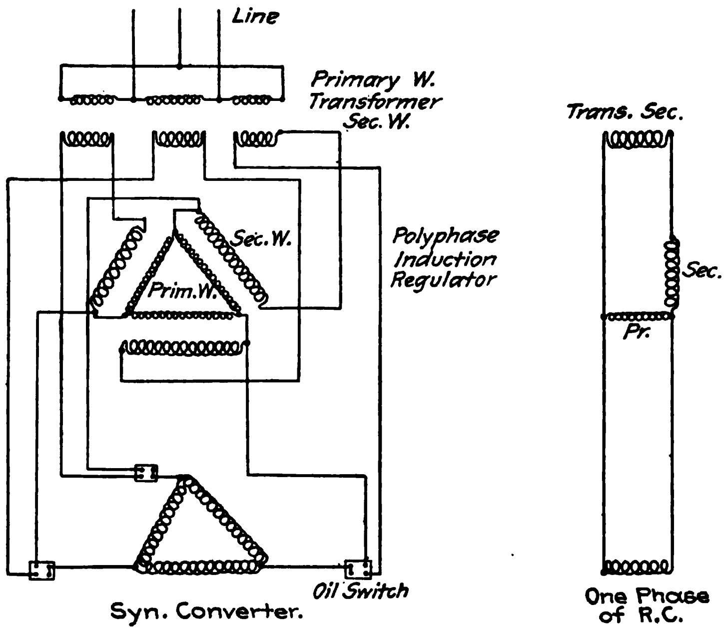


FIG. 148.—Connection of a Polyphase Induction Regulator with Synchronous Converter.

the magnetic fields do not change, their resultant value, and consequently the absolute value of the generated voltage, also remains constant. It does change the phase position of the resultant field, however, and hence the phase of the secondary voltage relative to the line pressure. The resultant line voltage is the vector sum of the generator and generated voltages. The

diagram in Fig. 147 shows the change of phase relation for this type of regulator.

Let EO represent the normal e.m.f. of a certain primary phase both in value and in time-phase position, let the radius of the arc ABC represent the constant voltage generated in the secondary phase winding of the regulator. With the primary coil directly opposite the secondary coil of the same phase, the voltage generated will be in reverse phase with that impressed, and will be represented by OD. The regulator will lower by the maximum amount, and the difference, ED, is the resultant feeder voltage. Since, however, the primary is rotated out of this position, the secondary winding considered will be partially excited by the next winding on the armatures, so that the voltage generated is not deducted directly from OE, but at an angle, as OC, and the feeder voltage is a resultant of EO and OC, or EC=EX. In a position of nearly 90° from the maximum lowest, the regulator will be neutral or no-boost, no-lower position, completing the full range of 180°, the armature is in an opposite field, of the winding surrounding the dissimilar pole, so that the secondary voltage, in phase with the primary, but in the same direction and the regulator is boosting. The resultant EA represents the maximum boost voltage.

Due to the rotation of a similar field produced by the currents in the series coils, the currents in the shunt-windings are constant, regardless of the position of the armature. For a given line current, the currents in the shunt-windings are taken from the line, or are delivered back into the system as the armature is rotated from maximum boost to maximum lower in the same phase relation as represented by the secondary voltage generated. (See Fig. 136.) The arrangement and operation are the same as for single-phase regulators. They are used in lighting systems to regulate the voltage in the feeders, and also in connection with synchronous converters. (See Fig. 148.) Induction regulators are either oil, air, or water-cooled, depending upon the capacity, pressure, and frequency of the line in which they are inserted.

CHAPTER XVIII

CONSTANT-CURRENT SYSTEMS

In series a.c. systems for arc and incandescent lighting it is necessary to maintain the current value of the circuit at a constant value regardless of the number of lamps. This maintenance is brought about by a constant-current transformer. The principle of the device depends upon the relative linear shifting of the secondaries with respect to the stationary primaries. Within certain limits the repulsion between the fixed and moving coils for a given position is directly proportional to the current in the coils. The transformer may be set for a given current value by adjusting a counterweight so as to balance the movable coil for a certain position.

Fig. 149 shows the interior connections of a 50-lamp air-cooled constant-current transformer, and one for 100 lamps is given in Fig. 150. Apparatus rated up to and including 50 lamps are built with two flat coils enclosing the central core. The lower coil, which is the primary, is fixed in position, while the upper one is suspended from the two inner arms of a double lever and can move freely along the central core. The outside arm of the lever carries a counterweight of such value that it will exactly balance the weight of the secondary coil minus the electrical repulsion due to the normal currents in the coils. Therefore, if the weight is reduced the current value is raised.

The 75 and 100-lamp transformers shown in Fig. 150 have four coils, two primaries and two secondaries. In the 75 and 100-lamp oil-cooled apparatus, and the 75-lamp air-cooled transformers the two primary coils are fixed at the extreme upper and lower ends, while the secondary coils are free to move up and down along the central core. The 100-lamp air-cooled transformer is arranged with the secondary coil stationary, and the primary movable. The two moving coils are balanced one against the other, and the counterweight serves merely to

draw the coils together in opposition to their repulsion force. A decrease in the counterweight produces a decrease in the current. The arc on the counterweight lever is made adjustable because the repulsion exerted by a given current in the coils is not the same for all positions of the coils, being greatest when

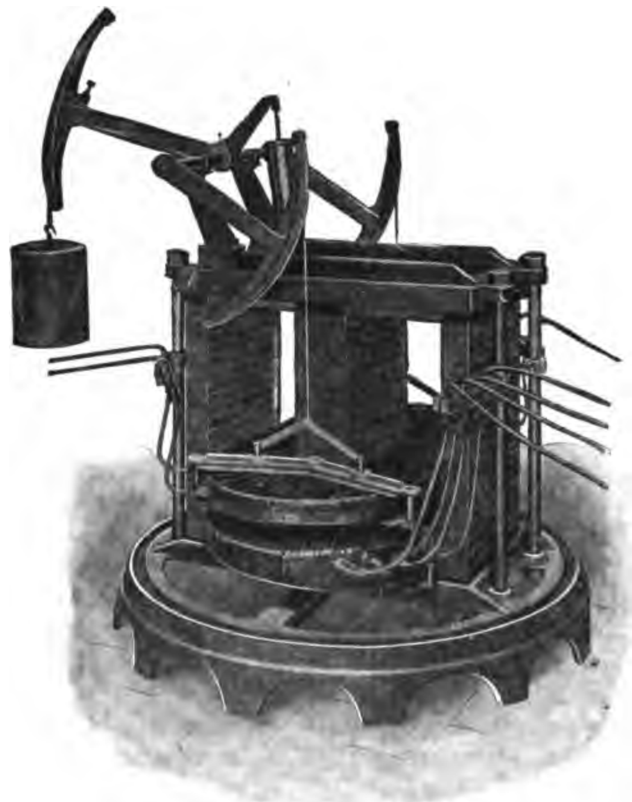


FIG. 149.—Internal Arrangement of an Air-Cooled Constant-Current Transformer with One Primary and One Secondary Winding.

the primaries and secondaries are close together. By means of the adjustable arc, the effective radius of the balancing weight is made to change as the coils move through their working range. When the current value is reduced below the normal the mutual repelling force diminishes and the primary and secondary coils approach each other, thus restoring normal

current. The opposite action occurs when the secondary current exceeds normal. The transformers, therefore, maintain the constant current for which they are set, regardless of the external resistance to which the coils are connected. The efficiency of these transformers at full load with arc lamps at 60 cycles varies from 96 per cent. for the 100-lamp type to 94.6

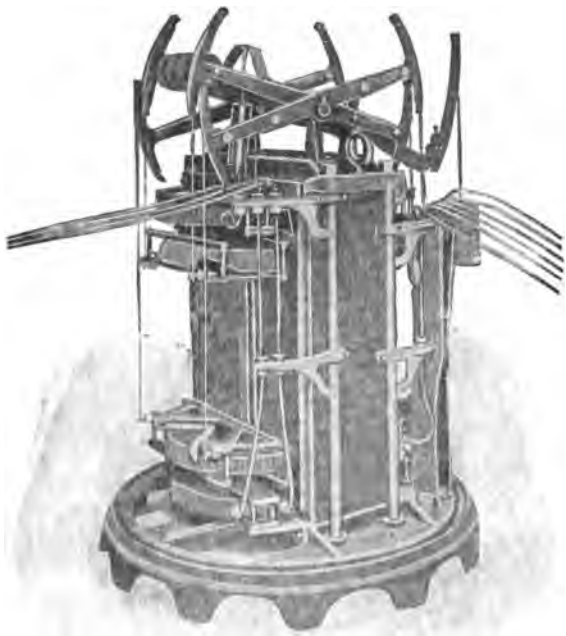


FIG 150.—Internal Arrangement of an Air-Cooled Constant-Current Transformer with Two Primary and Two Secondary-Windings.

per cent. for the 25-lamp type. The two primary coils of the 75 and 100-lamp apparatus are connected in series for 2200 volts, and in parallel for 1100 volts. An exception to this connection is found in the 100-lamp transformer in which the coils are arranged with a number of taps for use under partial load and full power-factor. These transformers are built for 1100 or 2200 volts, and the connections of the primary windings must not be changed. With the large transformer with two secondary coils, each of these coils is connected to its own cir-

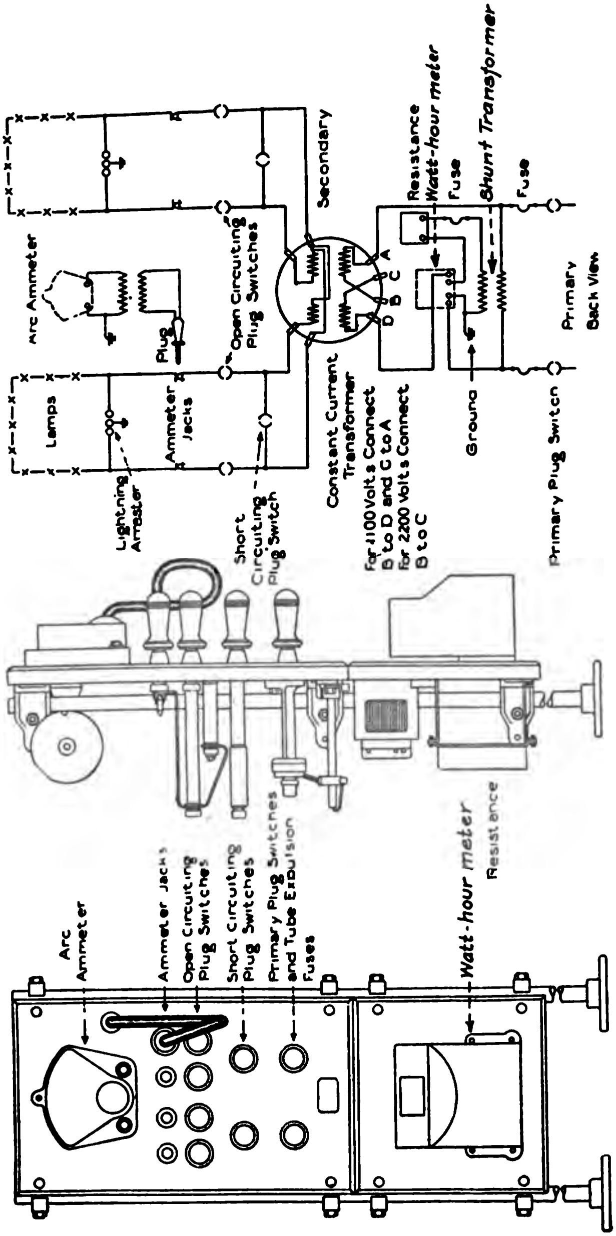


FIG. 151.—Connection and Panel Equipment for a Constant-Current Transformer for 50, 75 and 100 lamps.

cuit, while with the small type all lamps are connected in series on the same circuit.

The connections of a transformer having two primary and two secondary windings (75 or 100 lamps) is shown in Fig. 151, together with the circuit and switchboard. The primary side is connected to the outer circuit by primary plug switches. In a similar manner the individual lighting circuits can be connected with the transformer secondary, or can be short-circuited by means of a series of plug switches. The series transformer for the ammeter is connected into the desired circuit through an ammeter jack. The front and side elevations of the

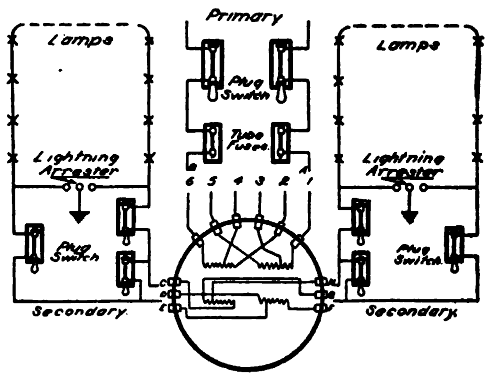


Fig. 152.—Connection of 100-Lamp Constant-Current Transformer with Two Secondary Coils and Taps for Partial Load at Full Load Power Factor.

board show the manner of mounting the plug switches and instruments together with their transformers and resistances.

Fig. 152 is the diagram of a 100-lamp transformer with primary and secondary windings provided with taps used for partial load at full power-factor. The connections of the instruments are omitted in this figure, but they are the same as those in Fig. 151.

In accompanying tables the connections for the different taps are given for different values of the load.

Each transformer calls for the following equipment:

1 ammeter.

1 series transformer (which may be omitted on boards for less than 35 lamps).

1 ammeter jack plug with necessary leads (for boards controlling 2 lighting circuits).

4 ammeter jacks (for boards controlling 2 lighting circuits).

2 sets open circuiting plugs and receptacles (for each lighting circuit).

1 set short-circuiting plugs and receptacles (for each lighting circuit).

2 primary plug switches with receptacles.

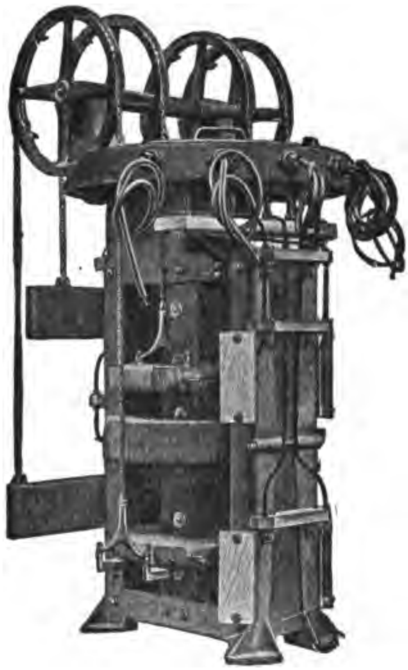


FIG. 153 —100-Lamp Oil-Cooled Constant-Current Transformer, Interior.

2 plug racks for the reception of idle plugs.

2 primary fuses.

The size of the fuses is such that they will protect the transformer from short-circuit. The above equipment is mounted on a panel of blue Vermont marble 28 inches high, from 16 to 20 inches broad. and set up 36 inches above the floor. An extra watt-hour meter is often inserted in the primary circuit to indicate the total amount of energy delivered to the trans-

formers. This instrument with its resistance is mounted on a base of the same width as the panel and 12 to 16 inches in height.

The interior connections and appearance of a Westinghouse 100-lamp oil-cooled constant-current transformer are shown in Fig. 153. It has one stationary primary winding and

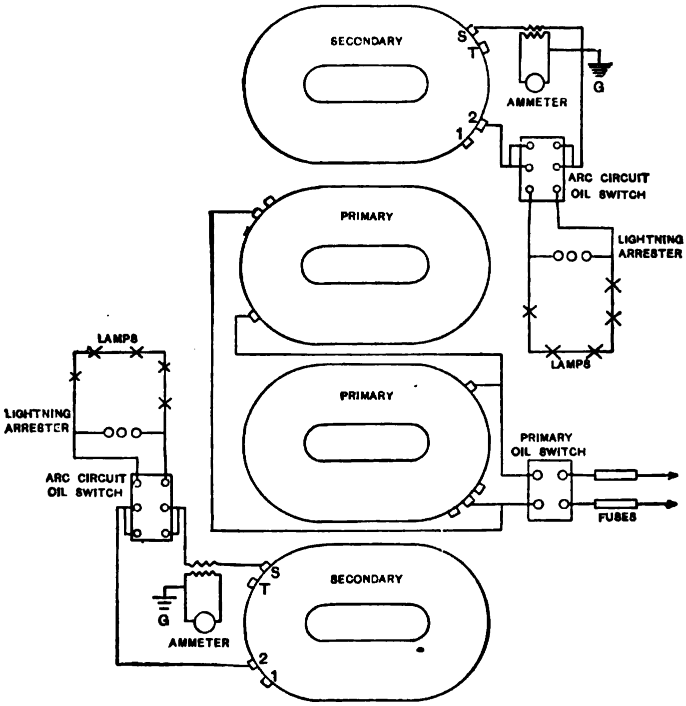


FIG. 154.—Diagram of Connection for 100-Lamp Air-Cooled Constant-Current Transformer.

two movable secondaries, each of which feeds its own lighting circuit. Both the primary and secondaries are provided with taps for connection to different voltages (within certain limits) and to partial load at full power-factor. To set the apparatus for a given amperage, small weights are added to the main counterweight. In constant-current transformers for 25 to 75 lamps with only one movable coil, an addition to the counterweight produces a falling off of the current, while in the type for 100 to 200 lamps with two movable coils, this

causes the current to be decreased in one coil and boosted in the other.

Fig. 154 shows the connections of a 100-lamp air-cooled

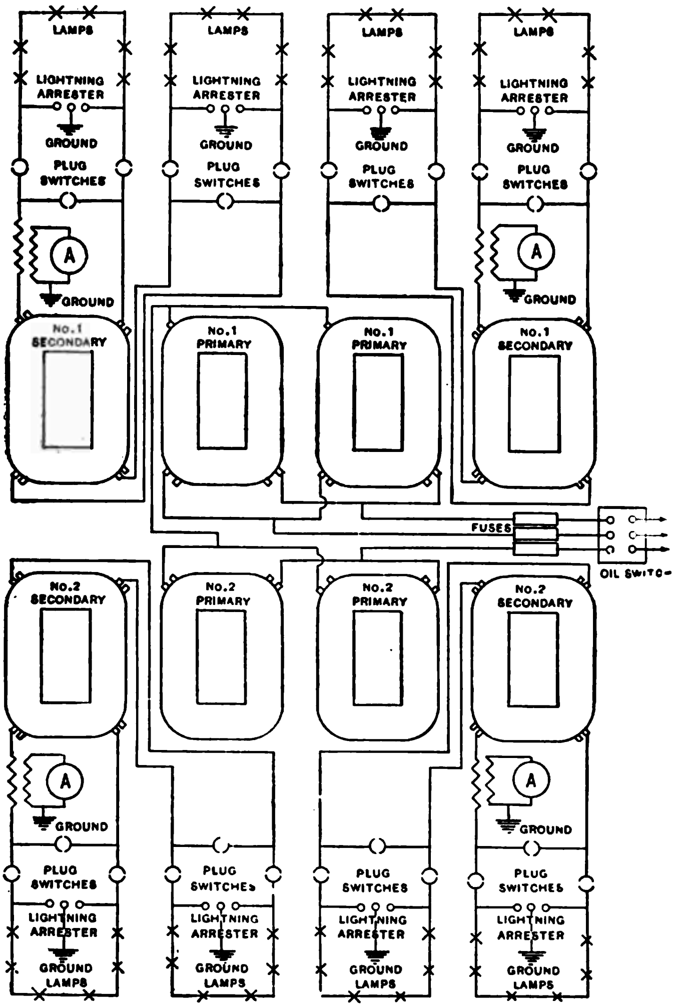


FIG. 155.—Diagram of Connection for Two 200-Lamp Oil-Cooled Constant-Current Transformers for Balanced Load on Three-Phase Circuit.

regulating transformer on a single-phase circuit. The connections of the primary side with the outer line, and of the arc lamp circuit with the secondary, are made through oil switches.

The oil switches for the lamp circuits are a combination of a double and a single-pole oil switch with separate handles, in which the double-pole part serves to cut the lighting circuit in and out, and the single pole to short-circuit the secondary transformer winding when starting and stopping.

Fig. 155 gives the connections for two 200-lamp transformers on a three-phase circuit, feeding eight lighting circuits. A set of plug switches connects the two secondaries of each transformer to the lighting circuits. There are also two primaries in each transformer. A three-pole oil switch connects the two transformers to the three-phase circuit.

CHAPTER XIX

STARTING COMPENSATORS

Induction or synchronous motors require a starting current several times as large as their full load current. With motors rated at more than 5 hp. such a starting current produces a considerable voltage drop and load variation in the circuit to which the motors are connected, and causes a disturbance in the general service. To prevent a rush of current during the starting period, starting compensators are connected in between the line and the motors during this interval.

Compensators for starting a.c. motors consist of inductive windings, one coil for each phase, which are provided with several taps and which supply a large current at reduced potential. Their effect is equivalent to that of a step-down transformer, and the product of e.m.f. and current on the line circuit is approximately equal to the corresponding product on the motor circuit. Each coil is placed on a separate leg of a laminated iron core, and is provided with several taps to obtain a number of sub-voltages for permanent connection to the starting switch of the motors according to their requirements. The three coils of the three-phase winding are connected in Y, and the line is joined to the three free ends of the coil by a controller switch, or for large machines, by an oil switch. During the starting period the motor is connected by means of the controller switch or a double-throw oil switch to the taps of the coil, and directly to the line during service. If the control switch connects the motor to the line, fuses are used to guard against short-circuit or overload, while if the oil switch is used, the switch itself provided with an automatic trip coil affords the necessary protection.

Fig. 156 shows the induction motor and compensator connections for a three-phase machine. Fig. 157 is a starting compensator built by the General Electric Company. The device shown is used for mounting on the wall or a panel, and in con-

nection with small motors the controller is placed in an oil vessel at the lower part of the compensator. In another type, used

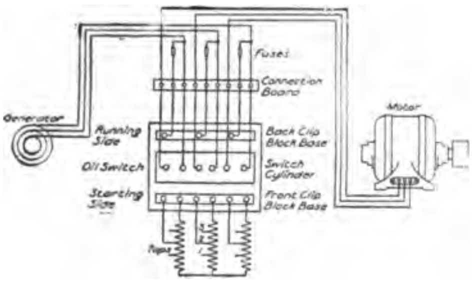


Fig. 156.—Connection of a Starting Compensator with a Three-Phase Induction Motor.

Fig. 157.—Starting Compensator.

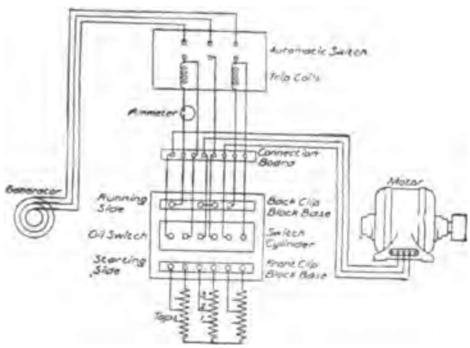


Fig. 158.—Connection of a Starting Compensator with a Separate Automatic Switch to Two-Phase Induction Motor.

for larger machines, it is mounted at the top. The lever of the controller has three positions, namely, "off," "starting" and "running." In the "off" position the compensator and motor windings are disconnected from the line, in the "starting"

position the switch connects the line to the free ends and the motor to the taps of the compensator windings, and in the "running" position the compensator winding is cut out, and the motor is connected to the line through the fuses or circuit breaker, which are mounted directly above the compensator.

Fig. 158 shows the connections of a three-phase induction motor with a starting compensator and automatic oil switch

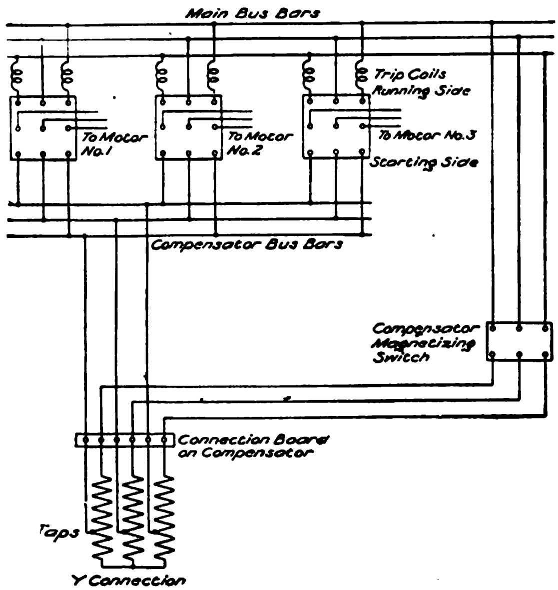


FIG. 159.—Connection for Starting a Number of Three-Phase Induction Motors from One Starting Compensator.

on the line side. In this diagram, the line is connected to the ends of each coil, and the starting connection of the motor to one of these ends and the tap.

In Fig. 159 there are shown the connections for starting a number of three-phase induction motors from one starting compensator, which is also joined to the line through an oil switch called a magnetizing or primary switch. The motors can only be started separately.

An extract of an information label included with a General Electric starting compensator is given below:

"The following directions apply whether the primary switch of the compensator is placed in the compensator box or on the switchboard. With either arrangement a double-throw switch is placed on the switchboard to connect the motor to either the compensator or the line." This double-throw switch can also be included in the compensator box.

To start the motor the following procedure should be observed: "Close the primary switch, and then throw the motor switch into the starting position. The motor should reach practically full speed in one minute with the switch in this position. Just before it reaches full speed, throw the motor switch into the running position and open the primary switch of the compensator. This primary switch should never be opened with the motor switch in the starting position. If the motor does not start immediately open both switches and adjust the compensator as follows: Connect the motor line in the compensator to the next higher connection on the coils, being careful to have all of the cables lead to corresponding taps on all the coils. If the motor fails to start again, connect the motor lines to the next higher taps and proceed as before. If it does not start with the highest tap connection, the load is either too great for the motor, or the line voltage is low." Where separate oil switches are used, the same mode of procedure should be followed.

CHAPTER XX

LIGHTNING ARRESTERS

LIGHTNING arresters serve the purpose of protecting transmission lines, machines and apparatus against the destructive influence of abnormal phenomena in voltage and frequency. All phenomena of this sort are defined collectively by Dr. C. P. Steinmetz as lightning. Such disturbances may be caused in three different ways.

1. They may be the result of exterior occurrences, such as electrical discharges between clouds or between clouds and earth. A special case of this is when the discharge strikes the transmission line. The influence of electrostatic induction of charged clouds or atmospheric strata and the collection of static charges from wind, rain, snow or mist is noticeable in the more or less dangerous phenomena observed in the rise of voltage and frequency.

2. Interior processes within the circuits, machines and apparatus will cause the same phenomena in changes of pressure and frequency as the outside disturbances so that they are properly included under the term lightning. Such processes may be caused by load variations, opening and closing of circuits, throwing machines into or out of circuit, or discharges by faulty insulation, short-circuit or grounding.

3. Interior or exterior lightning phenomena may be serious or quite harmless in their consequences, but their appearance in a system carrying considerable energy, though unimportant in itself, may cause an abnormal surge liable to prove detrimental to the installation.

The phenomena resulting from the causes just described may be classified:

1. A steady stress or gradual electric charge.
2. A strong impulse or traveling wave, and
3. A stationary wave or oscillation and surge.

Under the first conditions a series of discharges takes place in the lighting arrester, or if this apparatus does not operate properly, which is equivalent to its total absence, the insulation of the conduits is punctured at its weakest point. The harmful action, therefore, lies in the destruction of the insulation of the system and the serious consequences attendant upon short-circuiting or discharging thus made possible. It therefore becomes a function of the lighting arrester to take care of any excessive pressure in such a way that no disturbance shall be created in the system.

A strong impulse or traveling wave is generally caused by lightning striking a line or by discharge through arcing of accumulated static electricity. It may also result from spark discharge, sudden variation of load, or switching of apparatus. At the instant of their appearance such waves may possess considerable potential, and their influence may extend over a longer or shorter portion of the line, depending upon the inductance and condenser capacity of the line concerned. If such a wave is propagated it may be partially reflected at the entrance to stations or at points of electrical discontinuation of the circuit. The reflected wave will often form a new wave with the traveling wave, varying at certain points from zero to twice the value of the original wave. This new wave is said to be stationary. A break in the propagation of a wave or series of waves at the entrance to a station is made evident by electrostatic discharges, sparks and arcing at the cables and switchboard. Moreover, oscillations or fluctuations of varying frequency will occur in the transmission lines which result from a tendency to re-establish equilibrium of the energy flow after a disturbance has taken place. The danger from these fluctuations increases with the amount of energy carried by the system. The frequency of the fluctuations depends upon the resistance, inductance and capacity of the line.

The phenomena may occur singly or in combinations, one often causing the other.

Dr. C. P. Steinmetz defines the purposes of lightning arresters:

1. As guards against the entrance or origin of disturbances.
2. As prevention against spreading of disturbances.

3. And as means of taking up an existing disturbance and rendering it harmless, without in any way affecting the system, i. e., in regard to raising of voltage, etc.

The phenomena with which we have to deal under abnormal pressure and frequency are of such complicated nature, both in respect to the size, length, and form of wave, and to the time and relative order of their occurrence, that it has hitherto been impossible to design a protective device which will meet all the requirements imposed upon it, for given conditions of voltage and energy flow of the system. The various devices in use are of value only under the conditions for which they are designed. The controlling factors in their construction are the voltage and energy of the system, the kind of load and the overhead and underground installation of the transmission lines.

Of the devices tabulated below we will discuss only those occurring most frequently in practice, as their constant use has brought out some noteworthy improvements.

The following are the most common forms of protective devices:

1. Multigap lightning arrester without resistance, with series or shunt resistance, or with both.
2. Horn arrester, with or without series resistance, and with or without fuses.
3. Magnetic blow-out arrester.
4. Electrolytic arrester:
   (a) Aluminum arrester, with or without gap.
   (b) Liquid electrode arrester.
5. Choke coils.
6. Overhead grounded wire.
7. Overload switches.
8. Water jet from line to ground.
9. Coherer type.

MULTIGAP LIGHTNING ARRESTER

This device consists of a number of small brass cylinders mounted in a row on an insulated base with small gaps between them. One end of the row is connected to the line and the other end is grounded. Messrs. D. B. Rushmore and D.

Dubois* explain the action of the cylinders as that of small condensers, which are charged with varying amounts of potential according to their distance from the line connection, being maximum at that point and zero at the grounded end. When the potential difference between the first pair of cylinders increases beyond a certain limit, a discharge takes place between them. The potential of the second cylinder, being connected to the first by an arc, rises and may rise to such a point that it breaks down to the third cylinder, and the third to the fourth, and so on, till the arc has passed entirely across the arrester. This action shows the successive discharge of the arrester at a voltage in excess of the normal line pressure. As soon as all the gaps are bridged over by arcs, the line current starts and the distribution of potential is changed, following a straight line from a maximum value at line potential to zero. This indicates that the potential difference between all the cylinders is the same, and is much less than before the break-down. It is well known that to maintain an arc of alternating current across a gap the voltage must be at least high enough to break down the dielectric of the air gap each time the arc goes out at the end of a half cycle. The dielectric is greatly weakened by the heat produced by the passage of the arc. Therefore the voltage to maintain the arc need not be as high as that which originally broke across. The weakening of the dielectric depends upon the heat of the arc, and this in turn upon the boiling temperature of the metal of the arc cathode. A metal or alloy having a low boiling temperature is therefore chosen which at the same time will preserve its cylindrical form under the arcing action. Metal meeting these requirements is called non-arcing metal.

The size, material and number of the cylinders, and the spacing between them are so chosen that at the end of a half cycle the potential difference between the cylinders is insufficient to break down the dielectric resistance offered by the air gap. The arc therefore is extinguished after the first half cycle.

* "Protection Against Lightning and Multigap Lightning Arrester," Pr. A. I. E. E., March 29, 1907.

Another explanation for the non-arcing property of multigap arresters is given by Mr. Thomas in the discussion of the above mentioned paper. "It is a known fact that the arc starts by ionization through potential strain of the gases between the electrodes, by which ions are liberated. They are forced to move extremely rapidly by the high potential and produce other ions until finally there is such an increase of temperature and such an increased ratio of ionization that the quantity produced is sufficient to carry the normal arc current at a low voltage. At the instant the discharge and the normal current cease at the end of an alternation, in view of the close neighborhood of the conducting cylinders, the ions which would otherwise hold over until the return of the voltage are freely absorbed by the metal. Such ionization is very closely related to temperature, the high temperature very much increasing the ionization. Metals of low boiling point are used to keep down the temperature."

Arcing between any two successive cylinders consumes a certain amount of e.m.f. The successive losses in voltage thus incurred can reduce the discharge voltage between a certain pair of cylinders to such a value that no further discharge is possible between the remaining cylinders. The discharge therefore is only partial over a certain number of gaps. A complete discharge takes place when the initial voltage is so great that the successive discharges do not bring it to a value less than that of the spark voltage, or when the drop across the gaps is so small that the sum is not sufficient to affect the initial discharge voltage.

The drop in voltage between any two cylinders depends upon the value of the current. Messrs. Rushmore and Dubois state that "as this current is that due to the capacities which have been considered, it will be greater at high frequencies, and the fall of potential between the first and second cylinders will therefore be less. As the arrester gaps break down successively the fall of potential from one cylinder to another is less, and therefore such an arrester will discharge at a lower voltage for a higher frequency than for a lower." Multigap arresters without resistance discharge more readily at high frequencies than at low. In the same way that high frequency lowers the breakdown of multigaps by increasing the current of the spark, high

resistance, by absorbing e.m.f. when this current exists, decreases break-down. Resistance is most effective at high frequency in increasing break-down voltage, as at high frequency the charging current is greater, and therefore there is more voltage drop in the resistance. A resistance in series or shunt with the arrester limits the current and decreases the number of gaps. Series resistance limits the current under all conditions, but although in this way protecting the arrester, it is dangerous in case of a surge. Its action is questionable on account of the inductivity of the resistance, as in case of a high-frequency stroke, series resistance will prevent free discharge, so that no effective protection is afforded to the line and connected apparatus. By shunting a different number of gaps through different resistances the protection offered by multi-gap arresters for both high and low frequencies is assured, and the current between cylinders, as well as the number of cylinders themselves, is reduced.

An arrangement of this sort is shown diagrammatically in Fig. 160. As stated above a discharge across the gaps is facilitated by high frequency. This kind of discharge therefore follows the direct path across the gaps and not through the shunt resistances. With low frequency the discharge passes through a low resistance and the remaining gaps in series. If the frequency is still lower it chooses a path over a greater resistance with a less number of gaps in series, etc. This is explained by the fact that a discharge of low frequency is less opposed by a resistance than one of high frequency, the voltage being the same, and that it is still less opposed, the lower the frequency. When the discharge of low frequency breaks down, say over the high resistance, the entire voltage minus that lost in the discharged gaps acts upon the next gap division with its resistance, which is in turn broken down. A drop in voltage again follows and the remaining pressure acts upon the next division with its still lower resistance, where another discharge takes place, etc. In this way the discharge is accomplished in rapidly following parts from one end to the other of the gap row, and ceases either when the voltage is no longer sufficient to break down the next division, on account of the current in the resistance, or after the entire lightning arrester has been broken down. Breaking down of the arrester

is of course not to be interpreted as destruction of the instrument, but simply as a discharge over the apparatus.

This arrangement therefore acts as efficiently for low frequency as for high.

Fig. 161 shows the arrangement of a multigap arrester with shunt resistances for a delta or star connection without grounded neutral. Each of the three main legs consists of form V gap units, and is connected to one of the lines through

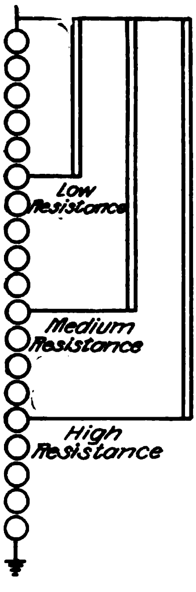


FIG. 160.—Multigap Lightning Arrester.

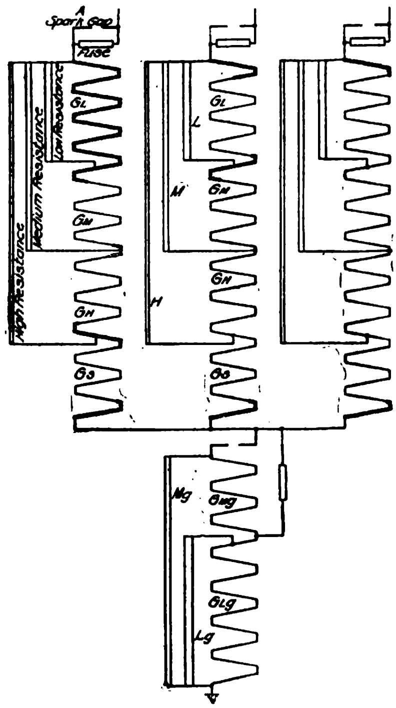


FIG. 161.—Arrangement of Multigap Lightning Arrester for 35,000 Volts Delta or Ungrounded Star Transformer Connection.

a spark-gap shunted by a fuse. The other ends of the legs are joined to each other by a common or multiplex connection, from which, for ungrounded systems, a fourth leg connects to the ground. In the arrester for grounded star systems, no fourth leg is added, the multiplex connection being connected to ground. The above diagram shows the three shunt resistances with their respective connections to the legs. The uses

of the fuses are explained in the paper referred to above as a protection of the apparatus against long continued high voltage on the line. When for some reason or other a high voltage in the line is not reduced by the discharges through the arrester, the device becomes exposed to destruction on account of the prolongation of the current. To prevent this the fuse is inserted, which by blowing out throws its spark-gap into series with the arrester. This allows the arrester to be adjusted to discharge at but a small percentage above the line voltage and thus to afford real protection. The blowing out of the fuse does not eliminate the protection afforded by the arrester, because the spark-gap still preserves the connection between the arrester and the line. It merely adds a factor of safety against the destruction of the arrester. It may be repeated that the shunt resistance forces discharges of different frequencies to seek different paths to ground, so that under all conditions about the same discharge voltage exists in the apparatus.

With a low-frequency surge, when the voltage rises, and before it reaches a dangerous value the gaps G_S arc over. With these gaps broken down the current of the arc across them is limited by the resistance to about one-sixteenth ampere, which gives about 80 volts drop per gap. The remainder of the voltage is consumed in drop across the resistance rods, and is thus applied across the gaps in G_H. Although this voltage is less than that which broke across G_S the series resistance is less, and approximately the same number of gaps will therefore break across this lower voltage. With G_S and G_H broken down the increased current gives a smaller drop in the gaps, but twice the number of arcing gaps are now in series. Therefore, the number of gaps in G_M is made the same as in G_S and G_H. These three sections should all arc over in succession at very nearly the same voltage. It has been found that when gaps are shunted by resistance and the resistance is low enough, dynamic current will not follow a high frequency across those gaps, but will shunt at once to the resistance, i. e., over L, and not over G_L. This shows that the resistance L is practically a series resistance as far as the safety of the arrester is concerned. Should the arc pass across all the gaps following a static discharge, the number of gaps is sufficient to extinguish the arc, and this holds with each resistance, and with the gaps

connected with it. That is, any current which may start across any of the resistances and the corresponding gaps would immediately be extinguished by that combination alone, without the shunting effect of other resistances, thus rendering the ex-

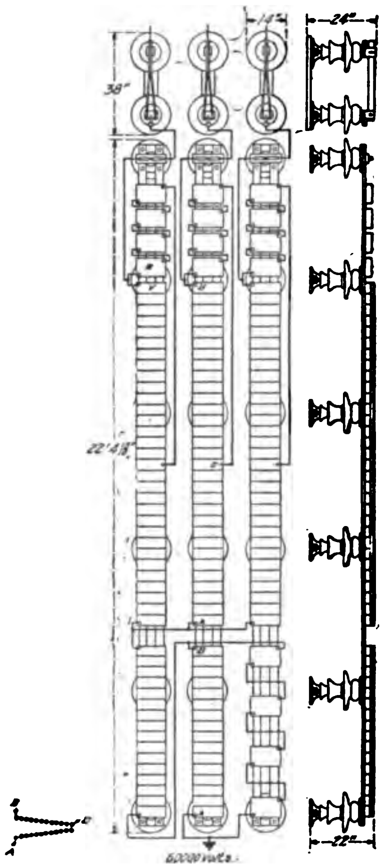


FIG. 162. — Multigap, Multiplex Alternating Current Lightning Arrester with Single-Blade Switches for 60,000 Volts Three-Phase Delta or Ungrounded Star Connected Circuits.

tinguishing of the arc doubly secure. The object of the multiple connection of the single legs of the arrester is to admit of discharge between the lines and between the lines and ground.

An equivalent needle gap is a gap which when connected in

parallel with a lightning arrester just fails to discharge, forcing the discharge to pass through the arrester. It is also defined by Prof. E. E. F. Creighton as a gap which when in parallel with the arrester possesses such a value as to cause at least 90 per cent. of the spark discharges to pass through the device and not more than 10 per cent. across the gap. This equivalent needle gap is an indicating device for the efficiency of a lightning arrester under discharges of varying frequency. The

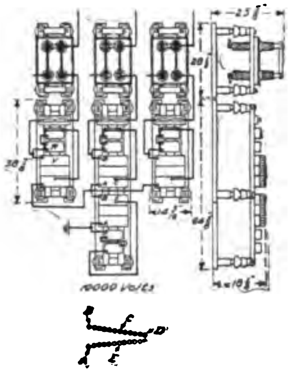


FIG. 163.—Multigap, Multiplex Alternating-Current Lightning Arrester with Single-Blade Switches for 10,000 Volts Three-Phase Delta or Ungrounded Star Connected Circuits.

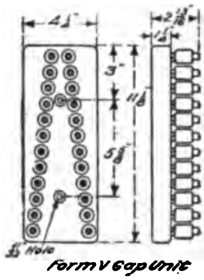


FIG. 164.—Form V Gap Unit.

smaller the value of the gap the more efficient is the protective device. If the laying out, material and mounting of the cylinders are correctly made, the equivalent needle gap must be less than the sum of all the cylinder gaps.

Fig. 162 shows the dimensions of type G. E. form V shunt-resistance multiplex a.c. lightning arresters with single blade switches for station use for 50,000 and 60,000 volts. The arrangement is for a three-phase delta or star connected circuit without grounded neutral. On account of its great length, the fourth leg between the multiplex point and ground is divided into three parts at the lower end of the three legs. A disconnecting switch is necessary to facilitate disconnection from the line for inspection or repairing. The gap units V and resistances R are mounted on porcelain bases supported by means of wooden strips on line insulators. The number of gap units

depends upon the length of the line, the nature of the country through which it passes, this referring to elevation, neighborhood of trees, passage through cities or open country, etc., upon the insulation of the line, and also upon the voltage and load of the system. Each transmission line therefore calls for special consideration. More precise adjustment of the arrester is made by means of the spark-gap between line and arrester.

Fig. 163 gives the dimensions of a similar device with double blade switches, built for 10,000 volts. Of the two disconnect-

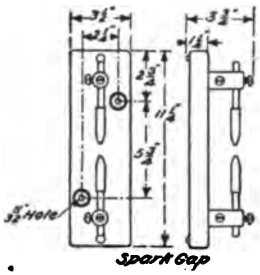


FIG. 165.—Spark Gap.

FIG. 166.—1000 and 2000-Volt Multiplex Multigap Lightning Arrester.

ing switches, which are mounted on a common base, one is for the lightning arrester, and the other for the line itself.

One of the gap units of form V is shown in Fig. 164 mounted on a porcelain base.

Fig. 165 shows the adjustable spark-gap which is used with each leg of a multigap multiplex arrester.

A double-pole multigap device for 3000 volts is shown in Fig. 166. In order to save space the shunt resistances are placed in slips directly over the gaps. Between poles the porcelain base is shaped to form a barrier. This device can be made suitable for use with 1000 or 2000 volts by short-circuiting one or more series gaps on each side of the ground connection, as shown in the cut.

Cables installed [illegible] generally lead covered so as to protect the insulation against rough handling or chemical

injury. Although such cables are not exposed directly to atmospheric disturbances, they are nevertheless subject to oscillations and surges caused by switching, load variation, etc., which may puncture the insulation at weak points. This is liable to produce sparking between the cables and their grounded lead covering which, on account of the energy back

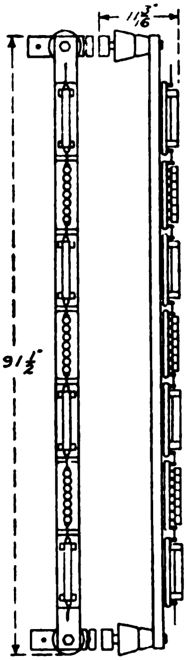


FIG. 167.—Alternating-Current Static Discharger.

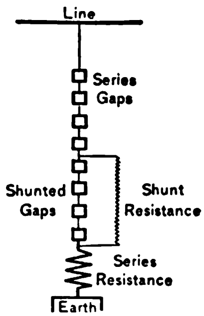


FIG. 168.—Diagram of Low-Equivalent Alternating-Current Lightning Arrester.

FIG. 169.—Low Equivalent Lightning Arrester.

of them, may result in burning up of the insulation of these and adjacent cables. Puncturing of the insulation and sparking may also take place due to the gradual accumulation of static charges on the lead covering, which are discharged from time to time without detection until finally the entire insulation becomes damaged. It is therefore desirable to ground the lead covering as often as possible. Sparking between cable and covering or ground brings about a series of successive impulses which must be eliminated from the cables by static dis-

chargers. In a combination of overhead and underground transmission lines of high capacity and inductance, oscillations of high frequency may occur without detection by the ordinary switchboard instruments, which may seriously endanger the insulation of the whole system. Protection against such contingences is afforded by the static dischargers. Multigap arresters also possess the capacity of protection against static discharges, a function which is accomplished by the high resistance with a few gaps in series, the remaining gaps and resistances not being necessary when only static discharges are required.

Fig. 167 illustrates a static discharger for 15,000 volts built on the lines of the multigap arresters.

In regard to the installation of arresters, a number of points must be kept in mind. For 5000 volts or more as much space as possible should be provided on the wall and in front of the arresters for their inspection and the safe operation of the disconnecting switches. Very often specially constructed high compartments or separate towers are provided for safe and efficient mounting of the high tension apparatus.

The following table gives the proper spacing between lightning arresters as recommended by the General Electric Company:

SPACING BETWEEN LIGHTNING ARRESTERS.
GENERAL ELECTRIC COMPANY.

Volts.	Distance in Inches Between Live Parts of Adjacent Phases.	Minimum Distance Between Centers (see Note).
6,000	8 inches	28 inches
10,000	8 "	28 "
12,500	8 "	33 "
15,000	10 "	35 "
20,000	12 "	37 "
25,000	18 "	48 "
30,000	22 "	52 "
35,000	26 "	56 "
40,000	28 "	62 "
45,000	32 "	67 "
50,000	36 "	72 "
60,000	40 "	78 "

NOTE.—If barriers are used, the width of barriers should be added to distances given.

The place where the arresters are mounted should be dry and warm, and before mounting all wooden parts and insulators should be thoroughly dried. It is advisable to place brick, asbestos or soapstone barriers between the legs on the line side of the multiplex connection. The latter connection and shunt leads for the resistances must be kept away from the barriers, and the arresters must be separated from the barriers by a space corresponding to the normal line voltage, as the

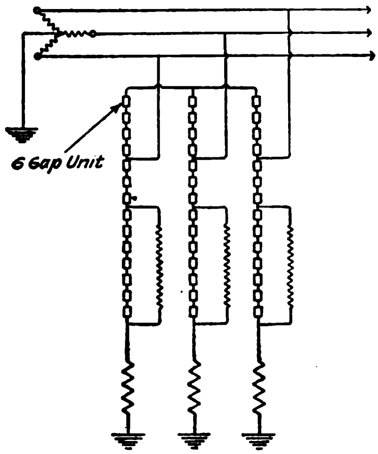


FIG. 170.—Connection of Low-Equivalent Lightning Arresters to an 18,000-Volt Three-Phase Star-Connected Circuit with Grounded Neutral.

FIG. 171.—Westinghouse Type C Lightning Arrester.

barriers are to be regarded simply as fire protectors rather than absolute insulators. There should be no doors in the front of barrier compartments. For single-phase only two legs, for three-phase three legs, and for two-phase four-wire circuits four legs are necessary, the leg between the multiplex connection and ground remaining the same in each case. Good ground connections are essential to proper operation of lightning arresters. These connections and the arresters themselves must be inspected from time to time to make certain that they are in proper condition.

The Westinghouse Company produces a lightning arrester similar to those above described, under the name of low

equivalent a.c. lightning arrester. This device consists of three parts, namely:

1. Series gap, a number of gap units in series.
2. Shunted gaps, and shunt resistance in multiple.
3. Series resistances.

The connections between the three parts are as in Fig. 168. The gaps are formed by cylinders of non-arcing metal mounted between two porcelain holders, and all gap units and resistances are mounted on a marble base. (See Fig. 169.) The action of this arrester is as follows: When a discharge takes place in which all the series gaps are broken down, it meets opposition in the shunt resistance and passes over the shunted gap to earth through the series resistance. The arc which momentarily follows the discharge is then withdrawn from the shunted gap by the shunt resistance, and aided by both resistances is suppressed by the series gaps. The potential at which a discharge takes place is determined by the number of series gaps, a sufficient number of which is used to withstand the normal voltage, and yet give a proper factor of safety for the severest service. The use of shunted gaps is to provide a by-pass for the lightning discharge which otherwise would meet opposition in the shunt resistance. The use of the shunt resistance is twofold, first, to withdraw the arc from the shunted gaps after the passage of the discharge, and secondly to reduce the volume of the arc so that the series gaps, too few in number to act successfully unaided, can, with this assistance, suppress the arc. The small series resistance limits the initial current that follows the discharge and thus prevents burning of the cylinders. An auxiliary spark-gap used in connection with the arrester permits adjustment within certain limits. Fig. 170 is a wiring diagram for the Westinghouse low-equivalent lightning arrester in connection with a three-phase line with Y connection and grounded neutral. Provision is made for easy discharge between the lines themselves. The space between active parts of adjacent arresters connected to different sides of the circuit should not be less, according to Mr. R. P. Jackson,* than the distance designated in the following table:

* R. P. Jackson, "The Protection of Electric Circuits and Apparatus from Lightning and Similar Disturbances," Electric Journal, April, 1908.

SPACING BETWEEN LIGHTNING ARRESTERS.

Voltage. Exceeding.	Voltage. Not Exceeding.	Distance Between Active Parts in Inches.
5,700	8,500	6
8,500	12,500	7
12,500	18,000	9
18,000	25,000	12
25,000	29,000	15
29,000	37,000	20

For low tension and particularly for distributors for lighting and traction, the Westinghouse Company uses type C

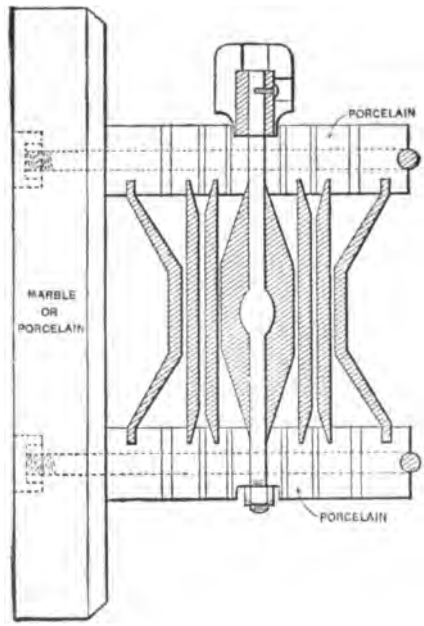


FIG. 172.—Metal Multigap Type of Lightning Arrester with Diverging Sides. (Stanley Electric Co.)

arrester, shown in Fig. 171. It is a double-pole multigap device with non-arcing metal cylinders, and is built for tensions of 500 to 1250 volts. It consists of seven independent cylinders carried on overhanging porcelain supports forming a unit which is mounted in a weatherproof cast iron case.

Another type of multigap arrester is shown in Fig. 172 as

produced by the Stanley Electric Company. The description of it given by Mr. N. J. Neall* is as follows: "It consists of a nest of concentric cylinders of brass or other high melting-point metal with flaring upper ends. The line terminal is at the center of this group, and the ground connection at the outside. When line current follows a static discharge, it takes the narrowest gap space of the arrester. At the same time a current of air is established through the many small holes in the bottom and top supporting porcelains. This draft pushes the arc upwards when, by reason of the attenuation of the arc and the greater cooling surface of these gaps, the short-circuit is broken."

HORN ARRESTER

This type of protective device has not proved of any great value in practice. It serves as an emergency device rather than as a normal protective apparatus. If the horn is connected to the line without restistance the arc short-circuits the apparatus for a time until it is ruptured by being driven to the upper ends of the horns through the magnetic and heat effects. If it is connected to a resistance of sufficient size to prevent it from causing considerable voltage drop by diminishing the current, its protective value becomes smaller. When a horn device discharges to ground without resistance the machines are thrown out of synchronism, and must be restarted. If a fuse is joined with the horn, the combination can offer protection for maximum voltage only as long as the fuse is not blown out, which results in lack of protection in storms when the fuses cannot be replaced. However, several fuses may be joined to the horn, so that when one is blown out, another can be inserted by means of a switch. But this arrangement makes the fuses, and not the horn, the actual protective device. The arc in the horn gap can cause more serious damage than the original disturbances. Under certain conditions it is apt to cause very high strains, so that the horn becomes the cause and not the preventative of a disturbance. The only proper application of horn lightning arresters is along transmission lines where they serve to protect the insulators, and not in the station. To protect an

* N. J. Neall, "Protective Apparatus," Electric Journal, June, 1905.

insulator, a gap of such value is chosen that will cause the sparking to occur across the horn rather than around the insulator. At all events if trouble occurs around an insulator the system is disturbed whether the gap is there or not, the only difference being that with the horn the trouble is of short duration, while without it the line may be tied up for a longer period of time until the broken insulator is found and replaced. With local stationary phenomena of high frequency the use of horns on the line is advisable. In constructing horns and proportioning the air-gap, care must be taken that the arc is

FIG. 173.—Horn Gap Arrester with a Disconnecting Switch.

driven upward and not downward, as not only the heat of the arc, but also its magnetic effect, tends to drive it outward.

Fig. 173 shows a horn arrangement used with an aluminum lightning arrester. Note that one side is built out in the form of a movable disconnecting switch lever.

The construction of the horn type of arrester as used by the American River Electric Company is shown in Fig. 174. The horns are of galvanized iron gas pipe and separated 2.25 inches for 40,000 volts. A jar of water covered with oil is used as a resistance in the ground wire. The oil of course is to reduce the evaporation. The arresters are mounted on wooden poles outside of the station.

Another diagram is shown in Fig. 175. This is the type used by the Standard Electric Company, of California, for 40,000 volt transmission lines. It consists of a gap formed between two horns and a tank of salt water, with an induction coil resistance in the ground connection. The horns are of No. 0000 copper wire mounted on ordinary line insulators. Copper

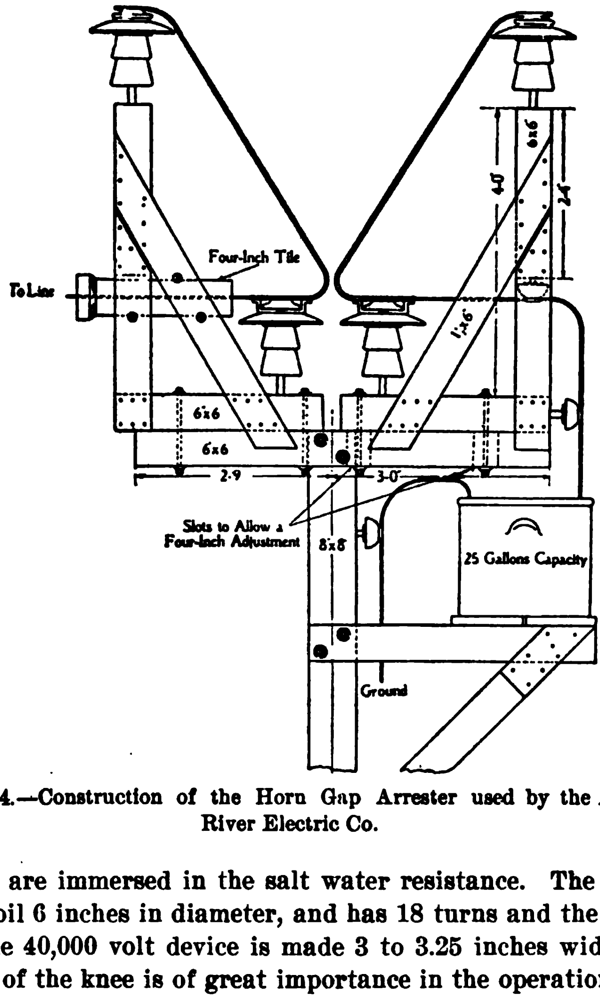


FIG. 174.—Construction of the Horn Gap Arrester used by the American River Electric Co.

strips are immersed in the salt water resistance. The reactor is a coil 6 inches in diameter, and has 18 turns and the air-gap for the 40,000 volt device is made 3 to 3.25 inches wide. The curve of the knee is of great importance in the operation of the device. Fig. 175 illustrates two horns which are bent improperly, the angle of the first being too small, so that the arc remains in the gap, and the second having too sharp a crook in

the knee, in which case the arc either remains stationary or jumps back again across the gap after having been driven upward.

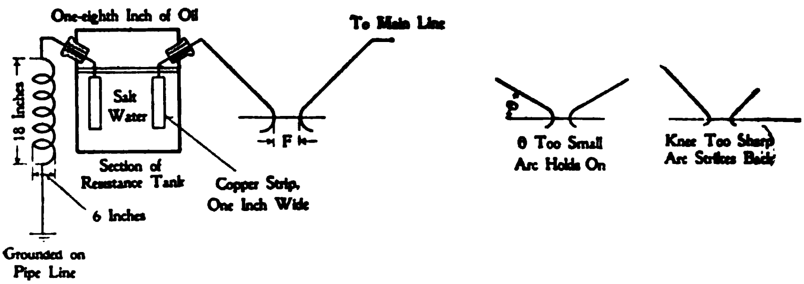


FIG. 175.—Construction of Horn Arresters used by the Standard Electric Co.

Another disadvantage of this type of arrester is the fact that at low voltages the gap must be made so small that it becomes difficult to maintain it constant, for dirt, dust and insects

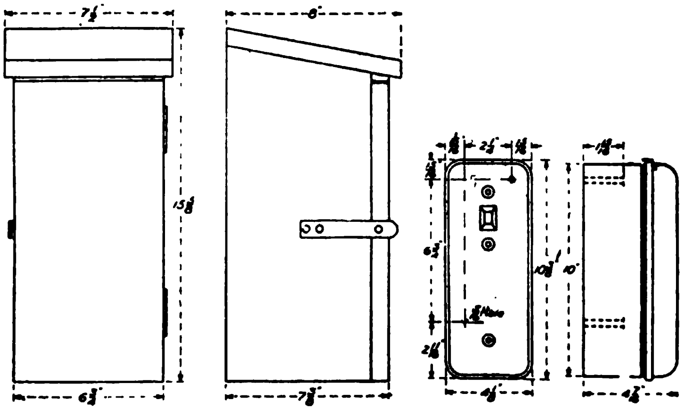


FIG. 176.—Type M D Direct Current Arrester.

quite readily collect in it and change its width, which materially reduces the value of the apparatus.

MAGNETIC BLOWOUT PROTECTIVE DEVICES

One of the first lightning arresters to come into practical use was that invented in 1884 by Prof. Elihu Thomson. This apparatus was so arranged that if a current followed a static discharge to earth, it was made to pass through the

winding of an electromagnet, which then excited a strong magnetic field about the gap, with the result that the arc was immediately blown out.

For direct current use this type of device is now used almost exclusively. The gap is in series with a resistance of low inductance. By providing a direct path for the discharge the possibility of short-circuit in the box in which the device is enclosed is reduced to a minimum when the discharges are especially severe. The connections to d.c. converters and feeders are shown in Figs. 1, 5, 13, 14, and 34. When the device is installed on the line it is usually enclosed in a wooden box supported on the poles carrying the transmission line. One of these boxes and the porcelain casing in which the arrester is mounted are shown in Fig. 176. This type is used for voltages up to 6000 volts. A spark-gap on top of the porcelain casing is used to adjust for voltage.

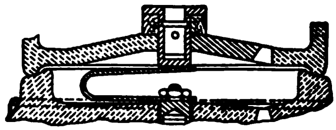
ELECTROLYTIC LIGHTNING ARRESTERS

(a) Aluminum devices.

As this type of apparatus passed the experimental stage only a few years ago, there has not been sufficient opportunity to test it under all conditions. But wherever it has been applied it has proven to be of particular value for static discharges or successive impulses. Although these devices do not displace the multigap arresters, their adaptability to taking up static discharges renders their use necessary if complete protection is looked for. As a rule they are connected to the busbars, thus protecting all the feeders, while the multigap devices give individual protection by being inserted in each individual feeder.

The construction of the aluminum type of arrester is based on the following principles. If an aluminum plate and another plate of some other metal be immersed in a suitable electrolyte, the resulting cell will have the property of passing current in practically only one direction. Only a very small fraction of the current is passed in the opposite direction until the applied voltage reaches a certain value. After this limit has been exceeded, however, the current rises much more rapidly with respect to the e.m.f. than Ohm's law would indicate. This action is explained by the presence of a thin dielectric hydrox-

ide film on the surface of the aluminum plate. If both plates were of aluminum, the action of the cell would be analogous to that of a steam safety valve. The device prevents the current as long as the pressure lies below a certain limiting value, but as soon as this limit is exceeded a very large current is established, which continues until the pressure again falls be-



Sketch showing method of placing one jar over another.

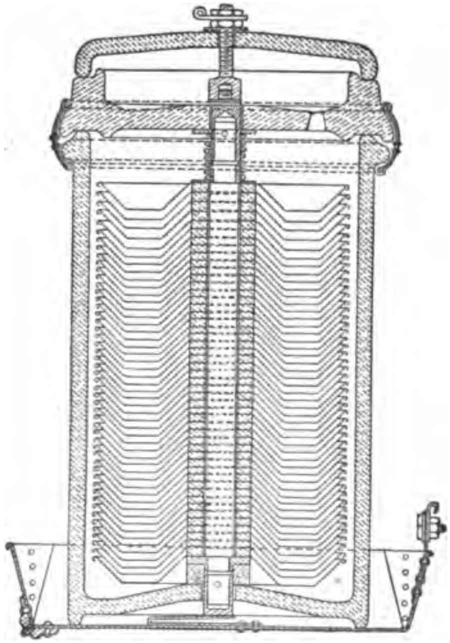


Fig. 177.—Electrolytic Lightning Arrester.

low its critical point. With a suitable electrolyte the above-mentioned dielectric film will be capable of resisting from 380 to 400 volts tension. Above this value it is broken down at innumerable points, and the current will thus be established. By connecting a large number of these plates in series arresters for from 4000 to 60,000 volts may be built up.

Fig. 177 shows how the aluminum plates are arranged in their cylindrical jar. The plates lie on top of each other, but are separated by insulation. The jar is made of stone-ware, and the cover is so shaped that another jar can be placed on top of it making a series connection with it so that the whole can be used for a higher voltage. After the electrolyte has been filled in from the top, a layer of oil is added to act as a seal to prevent evaporation.

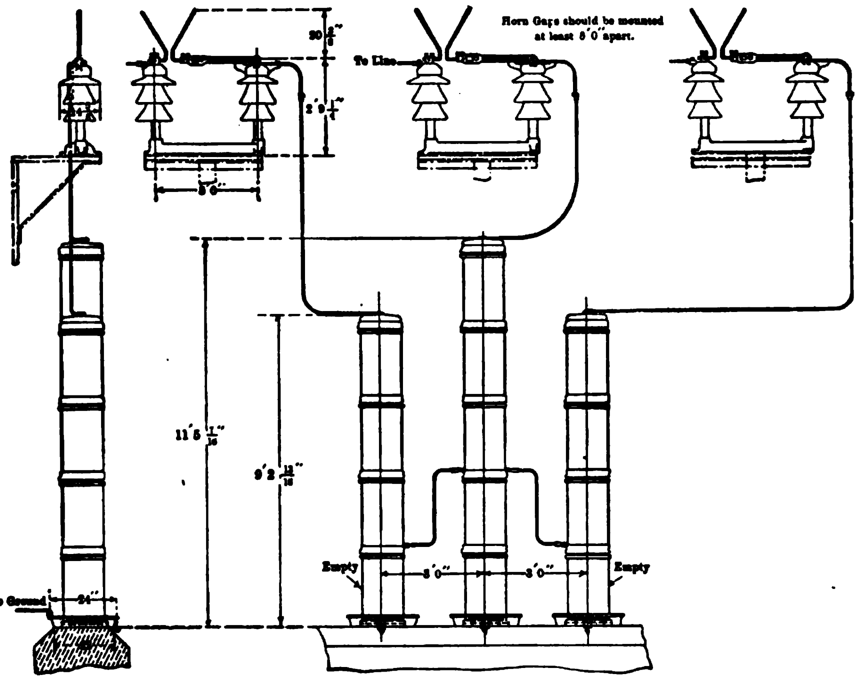


FIG. 178.—Electrolytic Lightning Arrester for from 53,000 to 66,000 Volt Three-Phase Circuits with Ungrounded Neutral.

The plates are in the form of trays so that the electrolyte fills the spaces between the trays, but not that between the trays and the jar. If one of these units were to be connected directly to the line normally small current through it would be sufficient to heat the cell, and would quickly spoil the plates. A spark-gap adjusted for the required voltage is therefore inserted between the line and the cell. Under normal voltage, therefore, the cell does not receive any current at all, and it is

only after the pressure has reached its critical value that the spark-gap and consequently the plates come into action. After an impulse has passed through, the arrester again becomes entirely inactive. During the discharge the cell consumes only a negligible amount of current, as the time of discharge is only momentary. For tensions under 13,500 volts the gap terminals are made of non-arcing metal, and a horn-gap is used for higher pressures. (See Fig. 173.)

A 66,000-volt arrester in series with a horn for three-phase circuits without grounded neutral is shown in Fig. 178.

The following equipment was recently installed in a 60,000-volt plant. Each branch of the three-phase circuit is provided

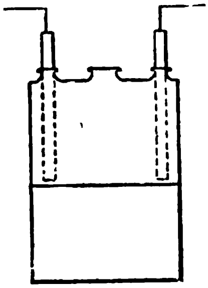


Fig. 179.—Liquid Electrode Cell.

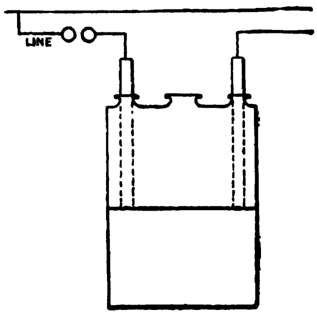


Fig. 180.—Liquid Electrode Arrester.

with three horns. The first is grounded by a 6-foot fuse, which is positive and effective in operation. And the second is in series with a resistance consisting of concrete blocks. The third is in series with an aluminum arrester which is expected to take up all static discharges and impulses in times of storm. If after a time it is seen that the aluminum arrester performs its functions properly all the other devices are to be discarded.

(b) Liquid electrode arrester.

The above name has been adopted for this type of apparatus to distinguish it from aluminum arresters, which, though they also contain a liquid electrolyte, operate in an entirely different manner. As was noted above, the discharges in the aluminum type are regulated by a dielectric film. In the liquid electrode type, however, according to the inventor, Prof. E. E. F. Creigh-

ton,* the electrolyte itself plays the main part. The following discussion must necessarily be restricted to a somewhat general description, as the apparatus has hardly emerged from the experimental stage, so that no results of practical importance have as yet been obtainable. The arrester discharges only at a critical limiting voltage, and at the same time reduces or entirely suppresses the machine current, at normal voltage, without a series resistance. A very high pressure of about 1500 volts is required to establish a current through the electrolyte from one electrode to the other, and the current is limited by the counter e.m.f. of the arc. One cell of a liquid electrode arrester is shown in Fig. 179, in which the electrodes form small gaps with the electrolyte. Experiments have shown that several hundred static discharges of 1000 amp. starting current will pass between the electrodes before any considerable machine current follows the discharges. The combined counter e.m.f. of all the cells is greater than the line voltage. Therefore, sparking will not cause arcing. The cell has a critical limiting voltage below which no discharge is possible and no current can exist. By adjusting the spark-gaps, the critical voltage of the cells may be regulated. If the electrodes dip into the electrolyte, an outside spark-gap must be connected in series with the cell in order to keep back the normal pressure, which is set for the given voltage limit. (See Fig. 180.) When a high pressure breaks down the spark-gap and reaches the electrodes, arcs are formed at their ends which drive the electrolyte away, thus automatically increasing the length of the arcs. Since the arc voltage is greater than the impressed voltage, the current quickly dies out. The series gap keeps out the normal pressure, whereupon the electrolyte recovers its original horizontal position touching the electrodes.

The arc voltage depends upon the length of the arc, and this in turn upon the value of the current causing the depressions in the surface of the electrolyte.

Objections to both types of electrolytic arresters have been raised, namely: that they will freeze when exposed to the weather, and that under heavy discharges they may be shat-

* "New Principles in the Design of Lightning Arresters," E. E. F. Creighton, Proc. A. I. E. E., March 2, 1907.

tered just as a tree or transmission line pole is destroyed by lightning. To prevent freezing the arresters may be placed in boxes or ditches below the freezing line. In regard to exploding all that can be said is that the device has been too little used to justify any conclusions.

REACTIVE COILS

High reactance in the line will break down any surge or wave trying to enter a station. Part of the wave is reflected, and part is allowed to pass. The latter portion must not exceed a value determined by the insulation of the station apparatus. A high reactance will also hold up a wave in point

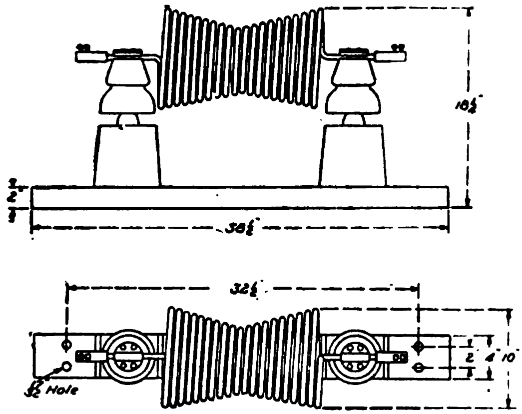


FIG. 181.—Choke Coils up to 35,000 Volts.

of time long enough to give the lightning arrester an opportunity to discharge.

A reactor is a device of high reactance designed to give protection against disturbances occurring when the line is carried overhead. Such coils are of no value for disturbances in underground cables or in the station. Each feeder in the station, however, should be provided with one of these coils. They are always used with lightning arresters, one arrester sometimes being placed on each side of the coil to hold up both inside and outside disturbances.

Strains at the transformer or other connections due to switching, grounding or short-circuit, make it advisable to pro-

tect the station apparatus by using reactors for the individual pieces or groups instead of building them into the main feeders to protect the whole station, as done heretofore.

Some engineers recommend the use of reactors of few turns, that is, of medium reactance. The turns are insulated from each other by air space which prevents permanent short-circuit, and they must therefore not be spaced too closely. In constructing these coils great attention must be paid towards providing sufficient radiating or cooling surface, in order that

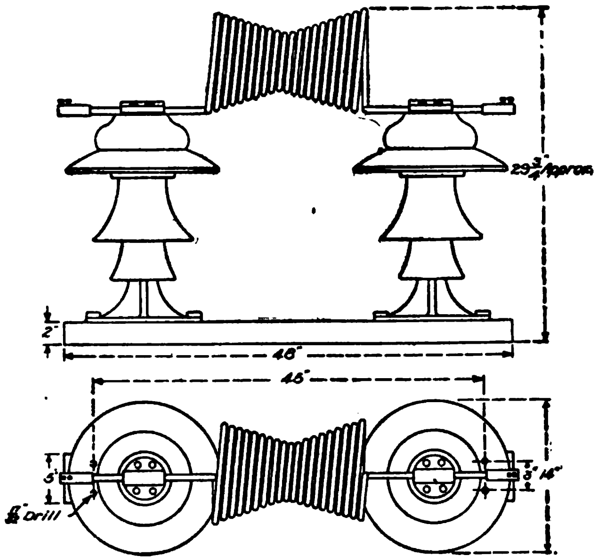


FIG. 182.—Choke Coils up to 60,000 Volts.

the heat generated may not weaken the insulation and cause a break-down at high pressures.

Figs. 181 and 182 illustrate two coils, one for from 6000 to 35,000 volts, 200 amp., and the other for voltages up to 60,000 volts and 200 amp.

In Figs. 34 and 35 there are shown a number of copper coils which serve the same purpose as reactors, and which are used for d.c. feeders.

To sum up: a reactor will protect apparatus in the station against high frequency fluctuations, but it offers absolutely no protection against static discharges or low frequencies. This

is due to the fact that the reactance of the coil is limited as it must be less than that allowable for the normal line voltage.

Fig. 183 shows the Westinghouse form 7 reactance coil, built for 2500 to 25,000 volts and 260 amp. capacity. They are used in connection with the low-equivalent lightning arrester. They are air-cooled and have a large number of turns, and therefore high inductance, since for high-tension apparatus a greater

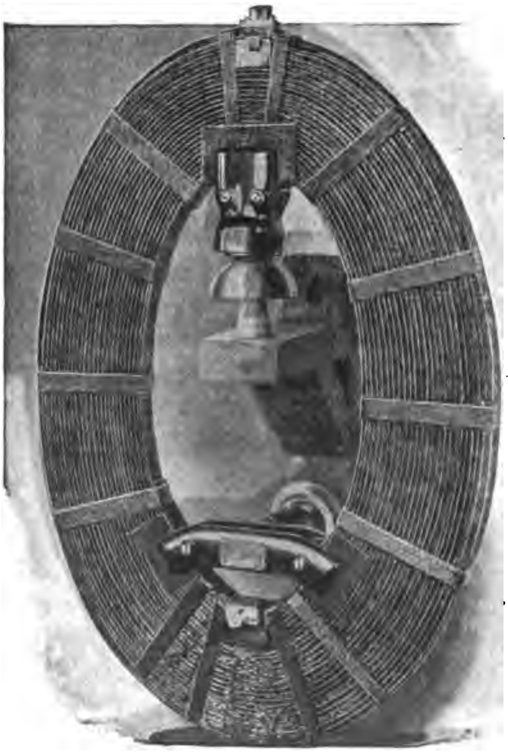


Fig. 183.—Choke Coil for from 2500 to 25,000 Volts Used in Connection with Low Equivalent Arresters.

"reactive effect" is required. For voltages over 25,000 volts the Westinghouse coil is oil-cooled. It contains a much larger number of turns than the air-cooled device, and hence has a higher inductance. Since there is a tendency with high inductance for the discharge to jump across from turn to turn, a high insulation of the winding is essential.

THE GROUNDED WIRE

Although this treatise is properly confined to central and substation installation arrangements, it may not be out of place to devote some attention to a protective device which serves mostly to shield the transmission lines themselves, but which affects the stations indirectly. This device is known as the grounded wire for overhead lines. In a body possessing perfect conductivity no disturbances of outside origin can be produced. If, therefore, a transmission line were encased in a grounded electrical conducting shell, electrostatic and other atmospheric influences would be eliminated. Precisely this is the condition attained in cables buried underground. But as the cables cannot always be laid in this position, the ground can be raised to the wire by an auxiliary grounded wire or series of wires. The theory of the shielding action of ground wires according to Mr. Ralph D. Mershon * is as follows:

The electrostatic induction of the clouds induces a bound static charge on the transmission line opposed in sign to that in the clouds, and at the same time liberates a free charge of the same sign. The free charge has a tendency to pass to earth. It will pass by gradual leakage over and through the insulation of the system provided the approach of the cloud is slow enough to give time for such leakage. If not it might puncture the insulation and thus pass to earth. The intensity of the charge will depend upon the potential of the line wires, due to the charge of the cloud. Suppose that there be near the transmission wires other wires parallel to them and grounded at frequent intervals. They also will be subject to the inductive action, and the charge set free upon them will pass to earth as fast as liberated, the bound charge of the opposite sign of that of the cloud remaining, and depending for its magnitude on the potential due to the cloud and the electrostatic capacity of the grounded wires. Under these conditions the intensity of the charge on the transmission wires will no longer depend only upon the potential due to the cloud, but upon the combined action of the charge of the cloud and the bound charge of the grounded wires. The potential of

* Ralph D. Mershon, "The Grounded Wire as a Protection Against Lightning," Pr. A. I. E. E., 1908.

the line wires will be equal to the difference of the potentials due respectively to the cloud and the grounded wires, and will in general be less than that due to the cloud. Suppose now that the cloud be discharged by a lightning flash to earth. The bound charge on the line will suddenly be set free, and if the ground wire were not present, this suddenly released charge might puncture the insulation in order to reach ground. But as auxilliary ground wires are provided there will be less tendency towards the puncture of the insulation of the system, because of the fact that the impressed potential of the line wires is less with the grounded wires than without them. The liberated charge in the ground wire passes to earth. This charge is obstructed more or less by the inductance of the discharge path, the effectiveness of this inductive obstruction depending upon the suddenness with which the cloud discharges. The worst condition would be that under which the charge on the ground wires could not pass to ground at all, in which case the sum of the two charges of the line wires will be just equal to that which would have existed if there were no ground wires.

The grounded wire affords even more effective protection against electrostatic accumulations from wind and rain, and against the potential difference between the atmospheric strata due to the different altitudes through which the line passes. The use of grounded wires, therefore, greatly relieves the stress which can be thrown on the station apparatus, and reduces the duty required of the station lightning arresters. It also protects the poles from direct stroke by leading the discharge to ground without damage to the line insulators. These wires are, to a certain extent, a protection against electromagnetic as well as electrostatic effects of lightning discharges in the neighborhood of the transmission line, as they are interlocked inductively with the main line, so that a part of the energy of the wave train is absorbed. The result is a rapid fall of the wave.

The grounded wires are usually of galvanized iron of sufficient size to offer a slight resistance to the discharge, and to be self-supporting. The latter property is important, for a break of the wire might cause considerable trouble in the transmission lines below it. The conductivity of the ground

wire has material influence since upon it depends the protection against the inductive effects of oscillations and sudden discharges. A $\frac{3}{8}$ inch standard steel wire grounded at least every 500 feet, and strung above the highest transmission wire within an angle of 45° to 60° to the outside wires, as recommended by Dr. C. P. Steinmetz, is the best form of this kind of protection. Two auxiliary wires are sometimes added on each side of the lines to increase the shielding action. All ground connections must be carefully made. Barbed wire is sometimes employed instead of the smooth kind.

WATER JETS

Protection with water jets is similar to that afforded by large resistances permanently connected into the line with the additional advantage of self-maintenance in case of a breakdown after a discharge. Water jets prevent to a certain extent the slowly accumulating static charges on the line. Their application is, however, restricted more or less to European use.

FIG. 184.—Multipath Arrester for Circuits up to 1000 Volts.

COHERER TYPE OF ARRESTER

This class includes the M. P. arrester, also called multipath arrester, as made by the Westinghouse Company for alternating and direct current. (See Fig. 184.) The static discharge passes in a large number of small streams over a carborundum block, the voltage across each gap being very small. The arrester is used for voltages up to 1000 volts. It discharges static accumulations and comparatively high tensions, but opposes the current at normal voltage.

A few words in regard to the installation of lightning ar-

resters are in place at this point. Lightning arresters are just as essential for protection against interruptions in service as any preventative of fire or accident in the station. In large systems a certain percentage of the cost of installation and of the yearly income is set aside for the purchase and maintenance of the best lightning arresters on the market.

In order to obtain maximum protection at minimum cost it is necessary:

1. To determine the location of the stations, transmission lines and apparatus, and to become familiarized with the character of the surroundings with respect to geographic position, physical characteristics, frequency of thunder storms, strength of prevailing winds, etc.

2. To know the nature of the system as to voltage, load and distribution, as for instance, if low tension a.c. or d.c., or high tension distribution with substations, or if grounded or ungrounded neutral is to be employed.

The Westinghouse Electric Company recommends that to obtain absolute protection arresters be placed at all points where apparatus is located. In circuits not exceeding 2500 volts it will usually be sufficient to place arresters at various intervals where good ground connections are available. These arresters should be so placed as to leave no considerable length of circuit unprotected, and should be more numerous in neighborhoods where circuits are exposed, as is the case in outlying districts where the lines are not protected by buildings and trees. Under average conditions satisfactory protection will be secured if no point of the circuit be more than 1000 feet from the arrester. For voltages exceeding 2500 volts arresters should be placed as nearly as possible at or near apparatus on exposed lines.

In all cases of circuits with ungrounded neutrals arresters rated at the voltages between line wires should be chosen, that is, for the maximum working voltage, and not for the voltage between line and ground. If the circuit has a grounded neutral, arresters should be chosen for a voltage 20 per cent. greater than the maximum voltage between line and ground. For example, for a circuit with grounded neutral having 16,500 volts between line and ground (approximately 28,000 volts between line wires) arresters for 20,000 volts should be chosen.

If, however, the transformers are connected in star in both high-tension and low-tension windings, arresters should be chosen as when the neutral is not grounded. They should always be placed on the line side of all apparatus.

Protection and maintenance of protective apparatus is of great importance for effective protection of the system. Broken or damaged parts should be replaced after each storm, including both arresters in the station, as well as insulators, poles, horns and other protective appliances located out of doors. All disturbances are recorded by placing paper sheets behind the arresters which also indicate if proper protection is obtained, and if any adjustment of the spark-gap and resistance is necessary. Proper ground connections which must be inspected from time to time are essential. Without these, all protective measures are of no avail. One method of making good ground connections is as follows: The ground wire, or what is even better, a copper strip, should lead directly to ground with as small a number of bends as possible, and the ground connection should be next to the arrester. In case the ground under the device is not suitable for a good connection, a proper ground is made at some other point which is then connected with the ground under the arrester. Copper sheets are recommended for the ground, thick enough to prevent wasting away, approximately 1-16 inch thick, and having at least 4 square feet of surface. The ground wire must be carefully soldered and riveted to this plate and then buried in powdered coke or charcoal in soil which is always damp. Dry, sandy soil should be kept wet by artificial means if this is the only soil available for the ground connection. Where plates are placed in streams of running or dead water, they should be buried in mud along the bank. Where there are metal flumes, pipes or rails it is advisable to rivet or solder the ground wires to them in addition to the connection to the copper plates, and when rails are utilized they should be thoroughly grounded. In view of the fact that it is advisable occasionally to examine the underground connections, it is desirable, when the ground plates are installed, to lay out exact plans of their location and that of the ground wires and joints.

CHAPTER XXI

HIGH-TENSION SWITCHBOARDS AND WIRING DIAGRAMS

THIS chapter is essentially a continuation of the chapter on low-tension a.c. switchboards where 250 to 600-volt circuits were treated. The intermediate chapters are inserted for the sake of discussing the devices and provisions for high and extra high tensions before a description of their mutual interrelation and connection with station arrangement is undertaken.

GENERATOR

The switching arrangement for 1150 to 2300-volt circuits corresponds in many ways to the 600-volt arrangements. In

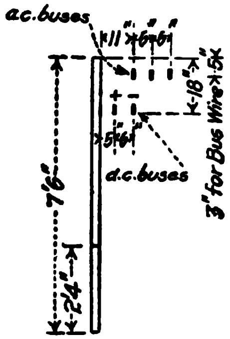


FIG. 185.—Location of Busbars or Bus Wires for Voltages from 600 to 6600 Volts.

most cases the oil switches are mounted on the board proper, and the measuring instruments are directly connected to the main lines, but it is advisable for higher tension to supply them through series or shunt transformers. Generator oil switches are non-automatic, while the feeder switches are provided with automatic trip coils. Three-phase generators or feeders require one or three ammeters according as the load is balanced or unbalanced. Potential regulators are often used

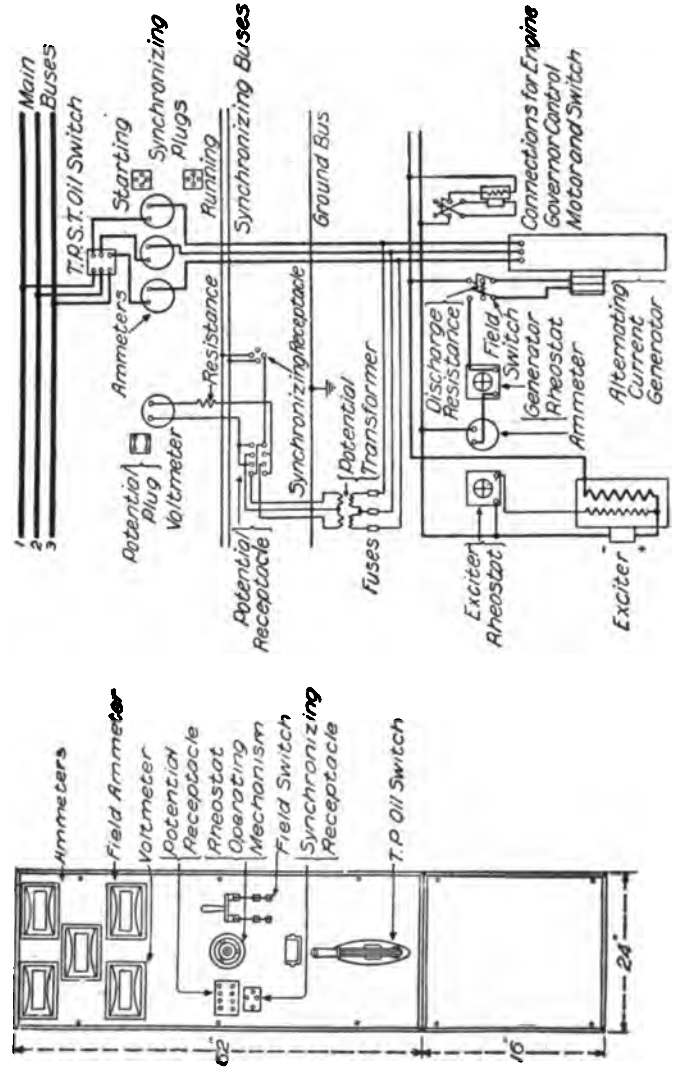


FIG. 186.—1150 and 2300-Volt Three-Phase Generator Panel.

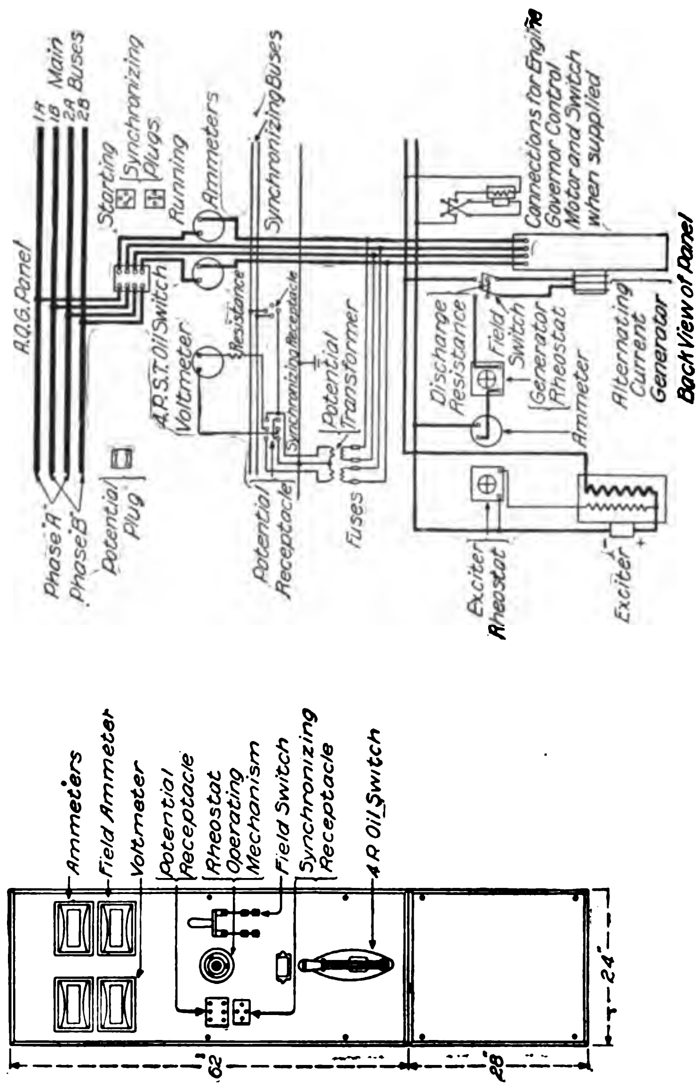


FIG. 187.—1150 and 2300-Volt Two-Phase Generator Panel.

with single-phase feeders in which case a compensating-voltmeter mounted on the board is required, in order to indicate the regulated voltage. For busbars either copper wire or copper bars are used according to the amperage of the plant, and these are mounted on insulators at the back of the switchboard near the upper edge. See Fig. 185, which shows the location of the a.c. and d.c. buses, relative to the board. The

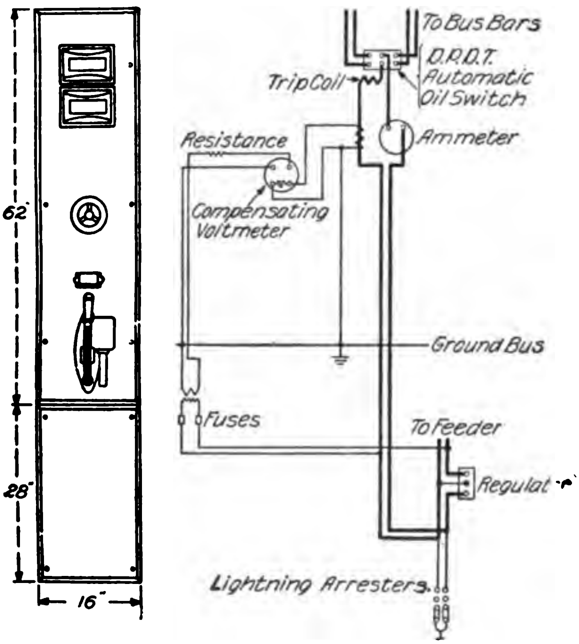


Fig. 188.—1150 and 2300-Volt Single-Phase Feeder Panel with Feeder Regulator.

illustration shows an example of the case where several generators are excited from d.c. busbars fed by one or more exciters.

A generator feeding one set of busbars is shown in Fig. 186. The voltage between any two phases is indicated by a voltmeter connected through a plug switch. The generator rheostat is operated from the board, and is mounted on it or away from it according to its size. The size of this rheostat depends upon the exciter current.

Fig. 187 is a diagram for a two-phase generator. In the two

figures note the difference in the position of the synchronizing plug switches for starting and running conditions of the machine. One synchronism indicator with these plug switches suffices for all the generators.

A single-phase feeder connected to the busbars through an oil switch is shown in Fig. 188. A potential regulator is pro-

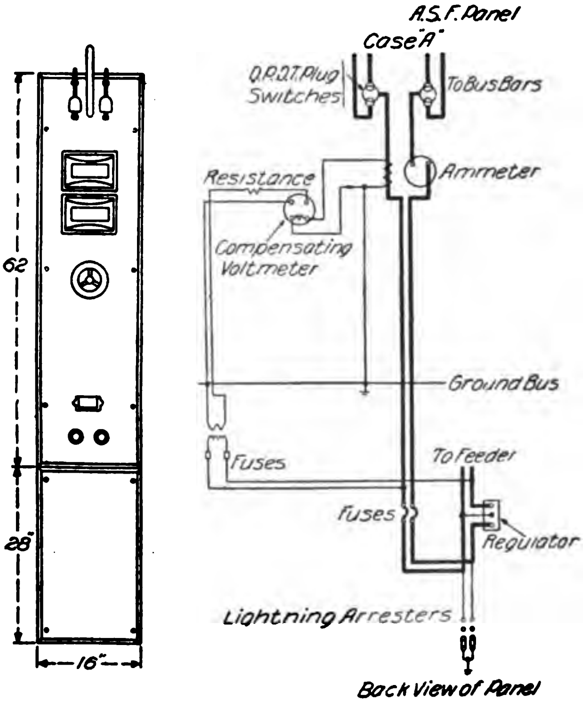


Fig. 189.—1150 and 2300-Volt Single-Phase Feeder Panel with Plug Switches and Expulsion Fuses.

vided, which is operated from the board through chains. Note the connections of the shunt transformers to the compensating voltmeter.

Fig. 189 is an arrangement similar to the one described above, with the exception that the oil switch is replaced by plug switches, and that protection is afforded by using fuses instead of trip coils. The type of fuse employed is that shown in Fig. 80. Lightning arresters are provided.

Two systems of connection for a high-tension generator are given in Fig. 190. In the one, the oil switch is operated by a motor through a small double-throw switch, while in the

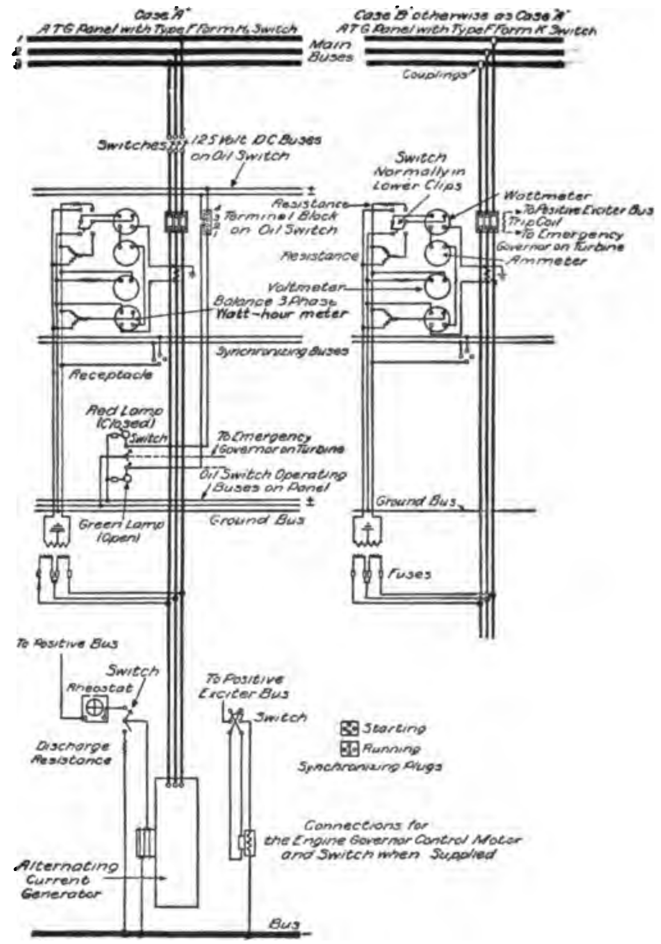


Fig. 190.—Wiring Diagram of Alternating-Current Generator Panel.

other, a toggle mechanism is used. A solenoid operated oil switch might also be used to replace the motor operated H3 switch.

In both cases the switchboard has the same equipment. One each of the following instruments and apparatus is used:

Ammeter, voltmeter, wattmeter, watt-hour meter, small double-pole, double-throw switch for the wattmeter, four-point receptacles for synchronizing connections, handwheel and chain

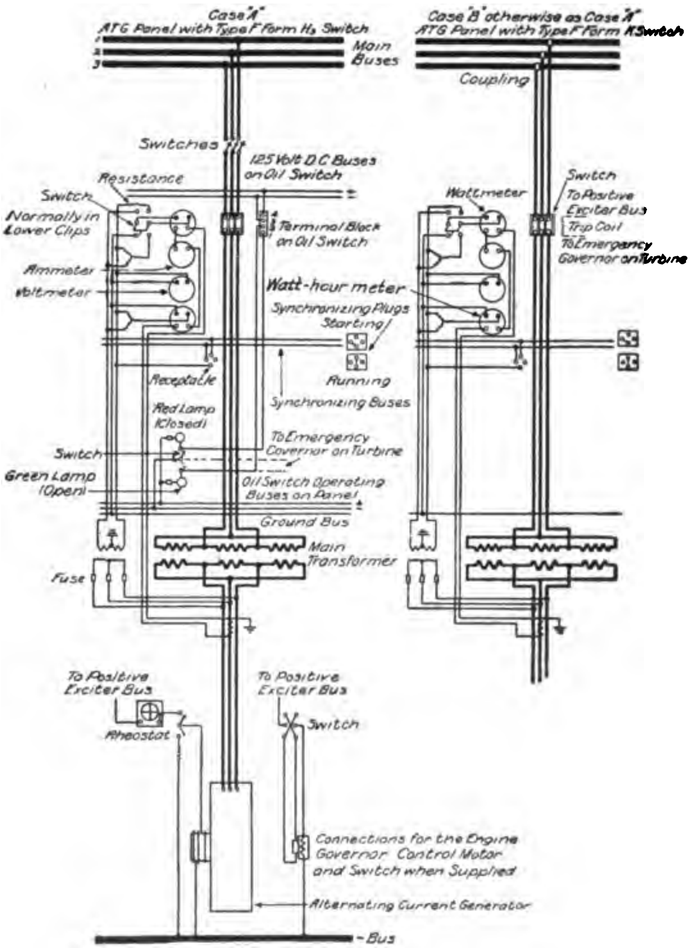


Fig 191.—Wiring Diagram of Alternating-Current Generator Panel with Step-up Transformer.

operating mechanism for field rheostat, single-pole single-throw carbon-break field switch with discharge clips, double-pole double-throw engine-governor controlling switch, single-throw, triple-pole non-automatic oil switch, series transformer,

and two shunt transformers. For a manually operated oil switch, the motor control switch is replaced on the board by the handle of the toggle mechanism. The series and shunt transformers are mounted away from the board because of the high voltages to which they are connected, and all high-tension wires are also kept well away from the board. The exciter,

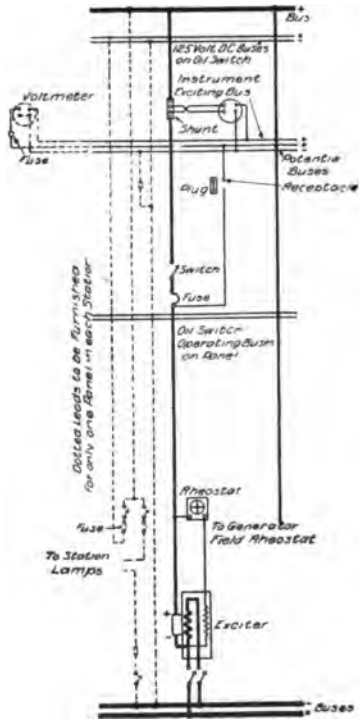


FIG. 192.—Wiring Diagram of Exciter Panel.

synchronizing, operating, and ground buses run across all the panels carrying instruments connected to them.

Fig. 191 is similar to 190 except that step-up transformers are connected to the generator. This arrangement is often used for high-tension long transmission lines in order to save copper in the lines. Series and shunt transformers are joined to the primary sides of the main transformers. Oil switches and busbar compartments should be mounted near to each other and in fireproof cells and compartments. (See Chapter XXII.)

If an alternator is to be thrown into parallel with a circuit, four conditions must be fulfilled.

1. The machine must run with precisely the same frequency as those in the circuit.

2. This frequency must remain constant.

3. The machine voltage must be in phase with that of the system.

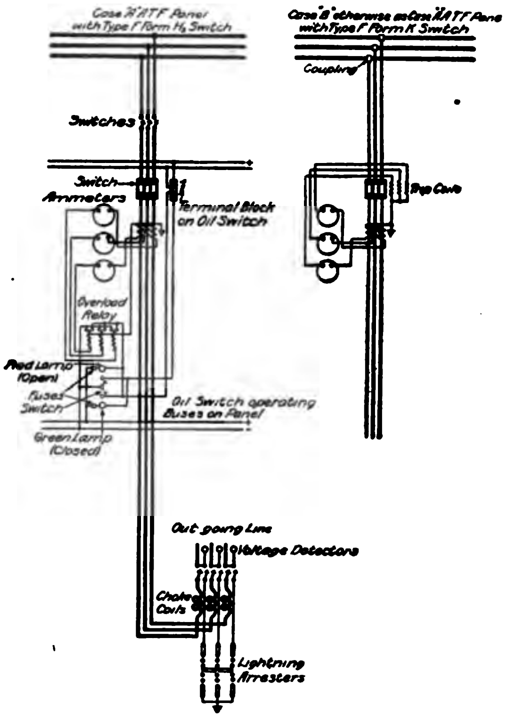


FIG. 193.—Wiring Diagram of Outgoing Line Panel.

4. The terminal e.m.fs. of the alternators must be exactly equal.

Successful parallel running of alternators results in proper load division of the machines, which should run without hunting.

The exciter supplying the generator field circuit may be driven by a steam or gas engine or by an induction motor fed from the main busbars. It is essentially a d.c. generator of

low voltage (125 volts), with similar connections. (See Fig. 192.) A fuse is inserted in the positive lead to take the place of the circuit breaker. One voltmeter will be sufficient for all the exciter machines. The positive exciter bus will usually be

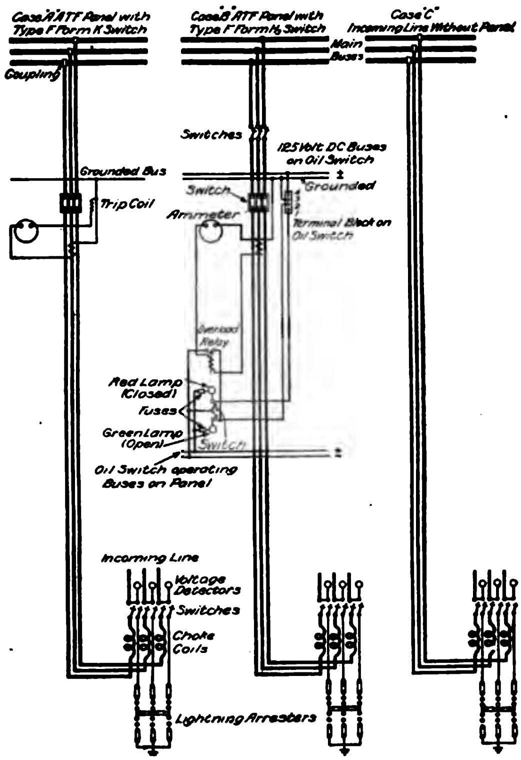


FIG. 194.—Wiring Diagrams of Incoming Feeder Panels.

found on the switchboard, while the negative is placed under the floor in the exciter foundations.

FEEDERS

An outgoing feeder with its connections is shown in Fig. 193. For unbalanced load, transformers are inserted in each leg, to be used for the three ammeters. Automatically actuated oil switches, when operated electrically, are tripped by relays, and if manually operated they can be tripped either by relays or directly from the series transformer. For overhead lines, lightning arresters and reactors are inserted. Additional pro-

vision to disconnect the feeders from the line is found in the disconnecting switches. Three ground detectors are connected on the line side of the feeders.

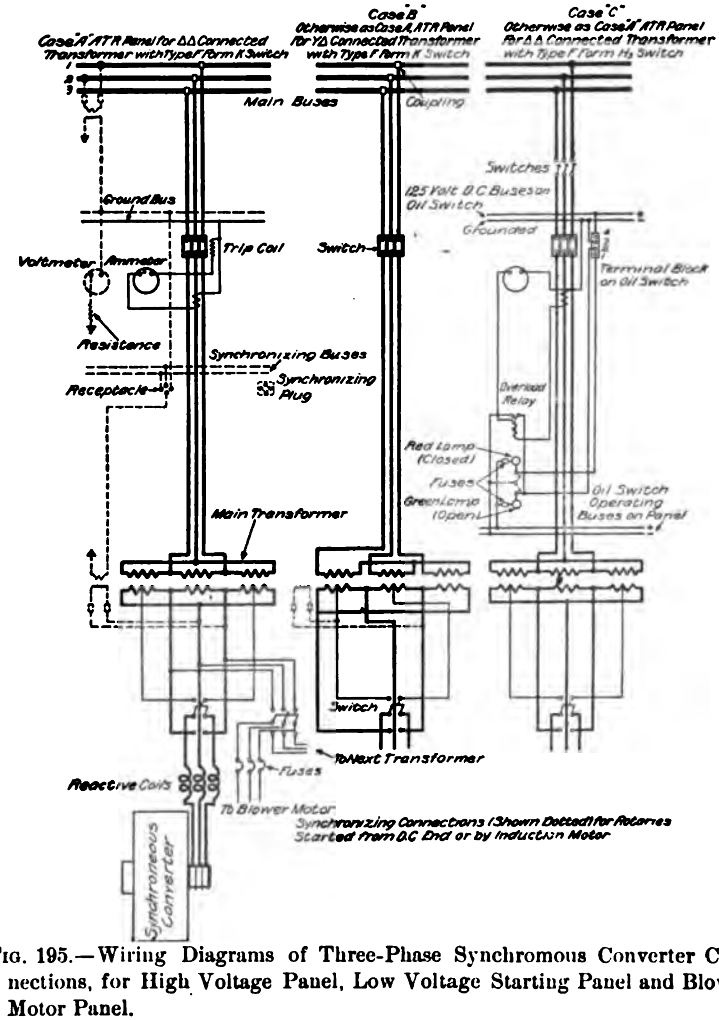


FIG. 195.—Wiring Diagrams of Three-Phase Synchromous Converter Connections, for High Voltage Panel, Low Voltage Starting Panel and Blower Motor Panel.

For incoming feeders only one ammeter with a series transformer is used. (See Fig. 194.) In some cases the central station feeder-control is sufficient, so that incoming feeders of substations require no further instruments outside of lightning arresters.

SYNCHRONOUS CONVERTERS

The d.c. side of converters has been fully discussed in Chapter III, so that only the a.c. side remains to be treated here. As previously stated a synchronous converter is built to interconvert direct and alternating currents. The connection to the alternating busbars of the system is made either directly or through a step-down transformer, according to the tension in the system. The latter method is the more frequent because the a.c. side of the converter must usually be joined to a 370 to 430-volt line, and if the converter is in a substation, a much higher transmission voltage is led to it. The a.c. generators also deliver current at high pressure. Wiring diagrams for a three-phase converter, with transformer, are shown in Fig. 195.

The starting voltage must always be reduced in order to prevent a sudden rush of current from the transformers, and this is done by means of the auxiliary taps from the transformer secondaries. In starting, therefore, the double-throw switch connects the converter with the auxiliary taps, and as soon as the machine has reached full speed it throws in the entire voltage of the low-tension side of the transformer. Special reactors are inserted between the transformer and the converter in order to prevent too great a starting current. These coils may be separately boxed up, or the transformer itself may possess the necessary reactance in which case the extra coils are omitted. It is customary to start converters of 300 kw. or less in this way, with the starting voltage at half the normal pressure. The starting voltage for 300 to 1500-kw. machines is from one-third to two-thirds the normal. If a.c. is used in starting, the armature windings act on the field-windings like a transformer primary on its secondary. A large number of field turns in comparison to the number of armature turns may generate a high value of e.m.f. in the former, which should be limited. This is accomplished by breaking the field-winding at a number of points by a multipole switch mounted on the frame of the machine. The connections shown dotted in Fig. 195 are used only when the converter is started on the d.c. side, or by an induction motor, in which case synchronous starting is essential.

Fig. 196 is a wiring diagram for a six-phase converter with a three-step connection to the low-tension side of the trans-

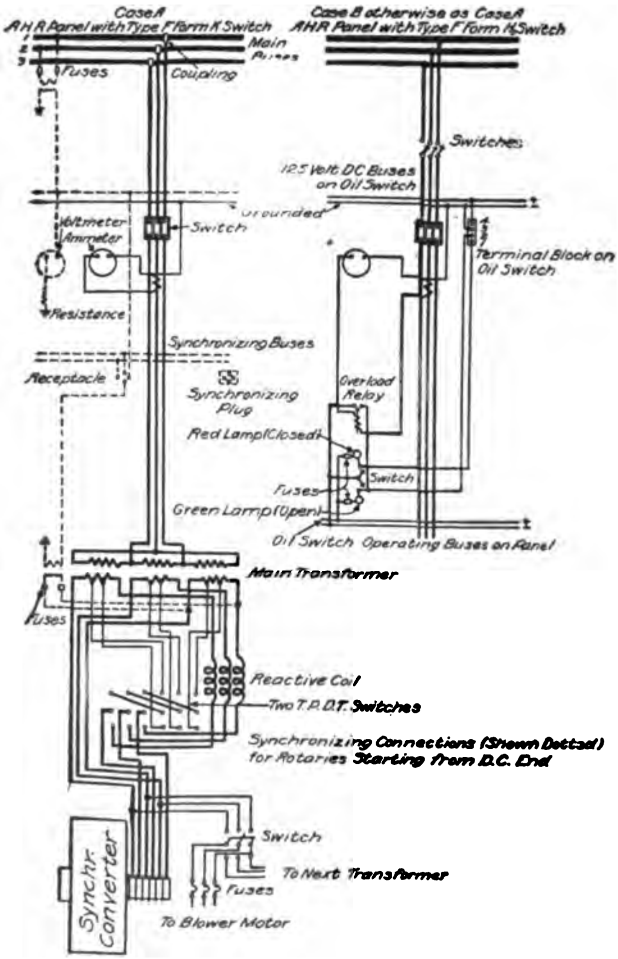


FIG. 196.—Wiring Diagram of a Six-Phase Synchronous Converter, for High Voltage Panel, Low Voltage Starting Panel and Blower Motor Panel.

former. If the transformers are air-cooled the connections of the ventilator motors are made as indicated in the figures.

The above method of starting is applicable in all cases for converters with low frequency, or when the fluctuations at

starting exert no material influence on the voltage regulation of the system.

The instruments and apparatus for the control of the a.c. side of converters are placed on two panels. A main board controls the high-tension side of the transformers, and therefore carries an ammeter, a controlling switch for the synchronizing oil switch and plug switches when necessary. The latter are used when starting from the d.c. side, or by an induction motor. The second panel is smaller, and is mounted independently near the converter. It carries the multipole switch which controls the low-tension side of the transformer, and hence the machine itself. The d.c. side has a switchboard of its own, as previously mentioned elsewhere.

If the system is such that it requires precise voltage regulation, it is advisable to start the converter by an induction motor mounted on the same shaft. (See Fig. 197.) This increases the certainty of starting, as each machine has an independent starter. Any accident to the motor, however, will cripple the converter. Before the machine is connected into the circuit it must be synchronized with the line. The synchroscope can be made to indicate whether or not the proper condition of synchronism obtains by properly connecting the shunt transformer and plug switch. A small additional switchboard will be required under these conditions to carry the starting switch for the motor.

The procedure for starting from the a.c. side of a converter is therefore as follows ("Standard Handbook of Electrical Engineers," p. 908):

1. All switches except the negative switch on the machine must be open.

2. Close the feeder oil switch which connects to the high-tension busbars. (This applies to the substations.)

3. Close the oil switch on the high-tension side of the transformer.

4. Close the starting switch of the low-voltage taps on the low-tension side of the transformer, i. e., the upper side of the double-throw switch.

5. As soon as the converter is in synchronism with the line, close the equalizer switch.

6. Close the series-shunt switch.

NOTE—If there are other converters on the line, the separate excitation of the series field seeks to establish a correct polarity by means of the equalizer buses. If its polarity is reversed it

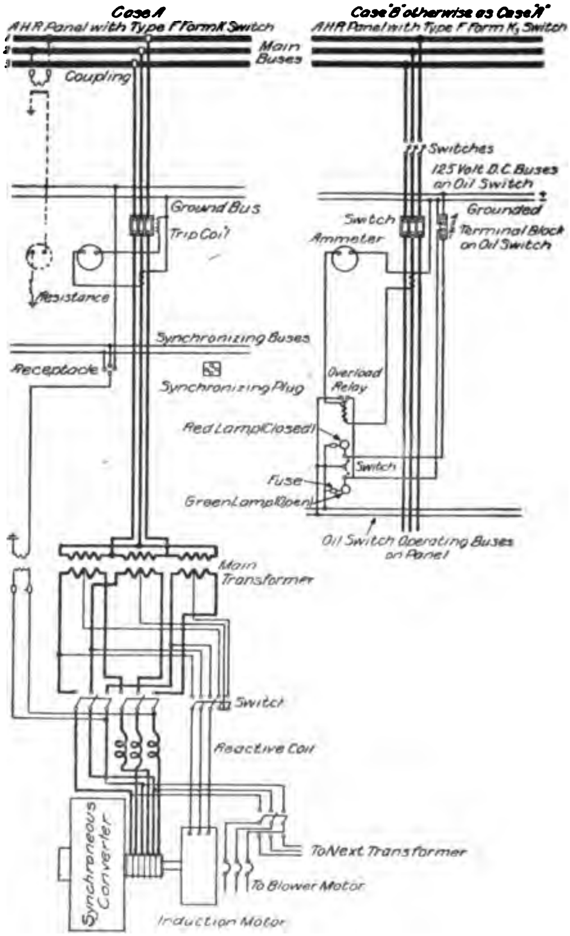


FIG. 197.—Wiring Diagram of a Six-Phase Converter with a Three-Phase Induction Motor for Starting.

can be quickly corrected by throwing over the field-break-up switch. The double-throw switch must be immediately reversed, however, since its lower position is only for reversal of polarity.

7. After the correct polarity has been obtained, throw the field-break-up switch into the upper position.

8. Throw the double-throw switch on the full voltage of the low-tension side of the transformer, by throwing the starting switch from the upper into the lower position.

9. Push up low-voltage release of circuit breaker and close the d.c. circuit breaker.

10. Regulate the field rheostat.

11. Close the main switch on the switchboard, and again regulate the field rheostat to obtain the proper load factor and voltage.

To shut down a converter open the d.c. circuit breaker, pull out and turn circuit-closing auxiliary switch to stop the ringing of the alarm bell; open the d.c. main switch on the panel; open the high-tension a.c. oil switch, allow machine to run down in speed until volts fall off to about 100 before opening the field-break-up switch or starting switch; open field-break switch, equalizer switch, series-shunt switch, and starting switch.

SYNCHRONOUS AND INDUCTION MOTORS

In the chapter on starting compensators, the switching arrangements for this kind of motor and the method used for starting them with the aid of compensators were discussed. If, however, the motor is so small that it consumes only a very small fraction of the station current, it is started and run directly from the busbars. A step-down transformer should be inserted if the voltage of the system so requires.

Two switchboards are required for the induction motor running an exciter. One is similar to the kind used for incoming feeders. The other is smaller and carries only a double-pole, double-throw starting switch, and is set up near the motor. The connections are shown in Fig. 198. The motor is connected on the low-tension side of a transformer-bank whose high-tension side is supplied from the main buses. At starting, the double-throw switch throws the motor in on half the transformer voltage, and when full speed is reached the entire voltage is thrown on.

Fig. 197 also shows the connections of the induction motor to the low-tension side of the transformer, and likewise the

manner of starting. The normal voltages at which the various induction motors are run are as follows:

Cycles.	Volts.
60	220–2080
40	550
25	440

Machines for higher voltages are built upon special order.

A synchronous motor is usually nothing more than a reversed alternator, whence it follows that the latter is often

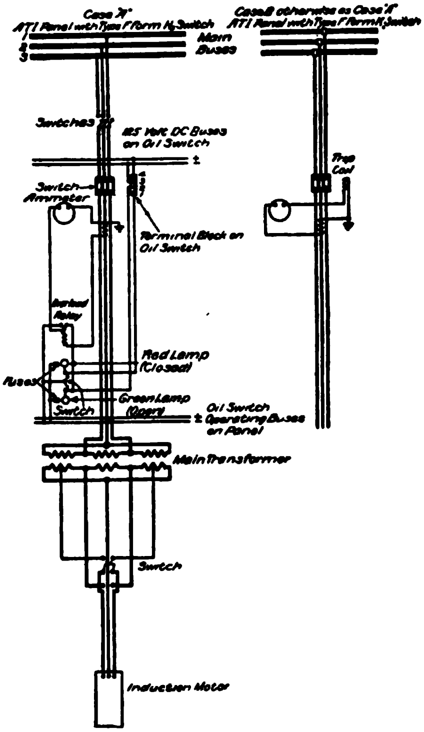


Fig. 198.—Wiring Diagram for Induction Motor Connection, High Voltage Panel and Low Voltage Starting Panel

used as such. These motors are preferred for motor-generator sets for the conversion of alternating into direct current, or into alternating current of different frequency, potential and phase.

In an induction motor, the power-factor is predetermined by its design and construction, and its current is always

lagging in phase. With the synchronous motor, on the other hand, the current can be made to lag or lead in phase by varying the field excitation. The synchronous motor, therefore, can be employed to advantage not only for full power-factor, i. e., for minimum current, but also to compensate the inductive load on the system, so that for the combined load at the given voltage and power output the system will operate at maximum efficiency.

This motor is started with the aid of a compensator, or, if frequent starting is necessary, a separate induction motor is used. The latter brings the synchronous motor to full speed, and the field is then excited at the line voltage. Whereupon the induction motor is shut off. During the starting period the field and armature windings of the synchronous motor act like those of a transformer. Therefore, if the field-winding has a large number of turns, so as to have high inductance, the winding is broken at a number of points by means of a multipole lever switch. (See Synchronous Converters.)

To reverse the direction of rotation of a three-phase synchronous or induction motor, it is simply necessary to reverse any two of the lead connections. For two-phase machines the connections of both leads of one phase must be reversed.

INSTRUMENTS

Instruments will be discussed only in regard to their application in a.c. practice without going into the respective advantages and disadvantages of the various types.

To determine the output of an a.c. generator, one or more ammeters are necessary. One instrument only is used under balanced load, that is, when the load consists only of rotating apparatus, such as converters or motor-generator sets, etc. Two ammeters are required for two-phase circuits, and three for three-phase under unbalanced load, such as current delivery for lighting. Another way of ascertaining the current in each feeder under these conditions using only one ammeter, is to join this instrument by means of plug switches and receptacles to a number of series transformers corresponding to the phases of the circuits. With alternating current an ammeter fails to give any information as to the distribution of the load on the various machines. A wattmeter for each

machine is therefore required especially for this purpose. A single voltmeter can be made to indicate the voltage of any generator by simply connecting it to the required machine by means of a plug switch. Sometimes a second voltmeter is connected to the busbars. This affords a means of calibrating the scales of the two instruments from time to time. Field ammeters are sometimes used as they give an easy way of ascertaining if anything is wrong in the machine itself. A power-factor indicator is not absolutely necessary, as a wattmeter can be made to perform the same function by using it with a double-pole double-throw switch. The wattless component can be read off directly if a polyphase wattmeter is used. One frequency indicator will do for each set of busbars. Since the introduction of turbo-generators these indicators have come to replace the tachometers used formerly to indicate the speed. To obtain a record of the generator energy output a watt-hour meter is a very efficient instrument.

The instruments which indicate synchronism for generators and converters are of great importance. By synchronous running of a given machine with respect to other machines, with which it is connected in parallel, is meant such a condition of running that the frequency and phase relation of the given machine are the same as the corresponding quantities of the other machines. Two machines have the same frequency when the number of alternations of their e.m.fs. in a given time are equal to each other. This condition is fulfilled when the product of the number of poles by the revolutions per minute is the same for both machines. Two machines have the same phase relation when the relative position of their armatures with respect to their field poles is the same; that is, when corresponding armature turns are opposite corresponding poles at the same time. When two machines have the same frequency, phase and voltage, there will be no unbalanced e.m.f., and consequently if they are coupled in parallel no rush of current will ensue. It is evident, therefore, that before machines can be coupled in multiple they must be synchronized. Instruments must consequently be provided to indicate when synchronous running is obtained, so that the connection may be made at the proper instant. Incandescent lamps and synchroscopes are the devices employed for this purpose. Figs.

199 a, b, c, and d are a number of diagrams for synchronizing machines with voltmeter, lamps and plug switches. In 'a' and 'b' the alternator is in multiple with the load. At the instant that the required condition of synchronism is obtained the lamps must be dark because the generator flux is

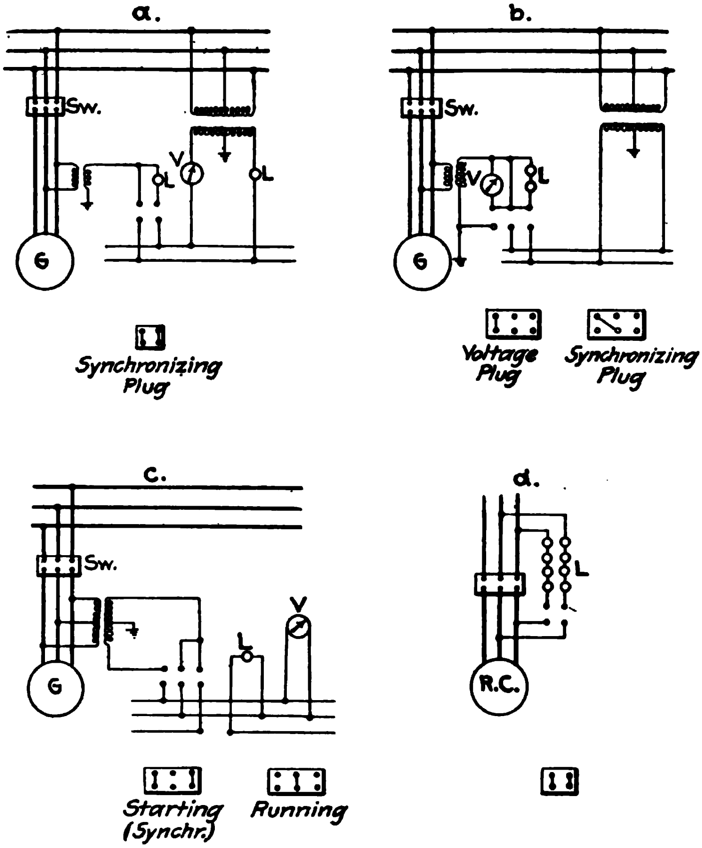


Fig. 199.—Signal Lamps as Synchronizing Devices.

then opposed to that of the system, and both generator and system have the same phase, so that they are balanced in the connection. The same conditions obtain in 'c,' where the alternator is in multiple with another machine. The lamp is darkened at the instant of synchronous running. In case 'd' a synchronous converter is to be connected to the system. As

synchronism is approached the pulsation through the lamps decrease in number, until the lamps go out at the instant when perfect synchronism is reached. The use of lamps has the disadvantage that a large difference of phase is required to make them burn, and that they do not indicate if the machine is running too fast or too slow. Moreover, since their use as synchronism indicators depends upon the fact that they become dark at the required moment, it is possible that an undetected

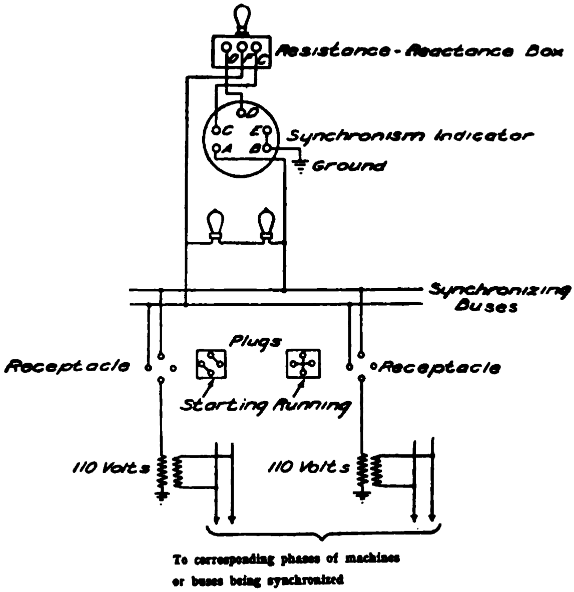


FIG. 200.—Connection for Synchronism Indicator with Grounded Secondaries on Shunt Transformers.

flaw in the lamps may give an erroneous indication as to the synchronism of the machine. A specially constructed synchroscope is therefore employed to advantage.

The functions of this instrument are: 1. Indicate if the machine to be thrown in is running faster or slower than those in circuit. 2. Indicate the difference in the speeds. 3. Indicate the moment when both machines are in synchronism. These functions cannot be performed adequately by lamps alone. Lamps are nevertheless used in connection with the synchroscope in order to facilitate the reading of synchronism

at a distant point. Fig. 200 shows a wiring diagram of a General Electric synchronism indicator with a set of lamps in parallel which darken when synchronism is obtained. The plugs are inserted in the receptacles according as the machine is in starting or running. In this diagram the secondary transformer windings are grounded. Fig. 201 shows the transformer secondaries not grounded. The dotted lines are the connections for the lamps when the latter are to be brilliant when synchronism is obtained.

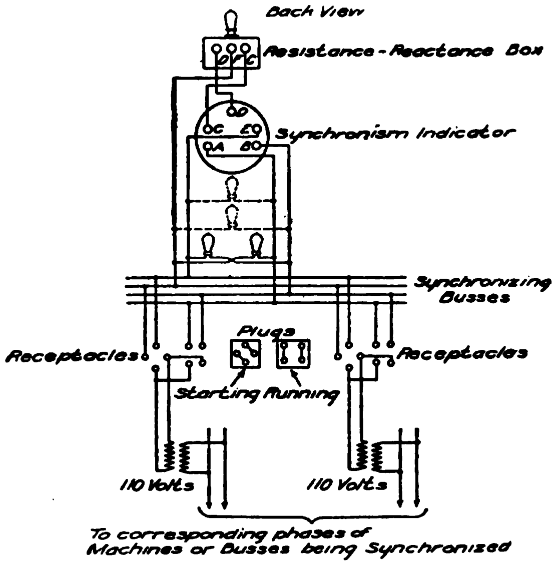


FIG. 201.—Connection for Synchronism Indicator with Ungrounded Secondaries on Shunt Transformers.

Lighting and power feeders should be provided with an ammeter, and in case a potential regulator is inserted in the line, a compensating voltmeter must be added in order to indicate the regulator voltage. Recording instruments are sometimes used for plotting the output of any given feeder. All instruments should be so placed that they may not come under the influence of outside magnetic fields. The instruments take their current from series or shunt transformers which are so designed that the current or voltage of the secondaries is the same for all transformers for the required ratio. Five amperes

is the normal current for the secondaries of series transformers, and 100 volts the normal voltage for shunt transformer secondaries. The latter are compensated so as to give a correct load ratio, while the former are compensated with regard to the loss with a given current. The load placed upon them should be light and of as small an inductive value as possible. All secondaries of instrument transformers should be grounded in order to eliminate puncturing of the insulation between primaries and secondaries. If the transformers are mounted away from the board, the secondary leads of a number of the transformers are led to the board together in conduits.

The Underwriters recommend the grounding of the neutral point of low-tension circuits when the conditions are such that the maximum normal voltage between the point connected and ground will not exceed 250 volts. This means that one side of a 250-volt circuit or the middle point of a 500-volt circuit may be grounded. For potentials above 500 volts, and not exceeding 6600 volts, a safety gap should be used in the ground connection. This applies to transformers whose ratio of transformation is five to one or greater. The safety gap is of course set for the particular voltage to which it is connected.

SWITCHBOARD PANELS

In high-tension stations all instruments and control and operating apparatus are placed on a switchboard which may be selected in any one of three forms, namely: 1, panel; 2, benchboard, or desk, and 3, control pedestals and instrument posts. The material used for panels is white Italian or blue Vermont marble, or slate. The stone to be used should be free from metallic veins. These materials are fireproof and good insulators, and are strong, reasonably cheap, easily worked, and of agreeable appearance. The panels are generally carefully selected so as to match the colors of adjacent parts. White marble has the disadvantage of showing dirt, oil spots and scratches, which are difficult to remove. Soapstone is too soft, and is difficult to work up to make a good appearance. It is therefore not used for panels, although it is extensively employed for other electrical construction purposes in the station. The finish given to marble or slate may be either a high polish,

black enamel, dull black, or marine finish. The standard thicknesses are 1.5 in., 2 in., or 2.5 in., with a 0.375 in., or 0.5 in. bevel. The installation for high-tension panels is similar to that for low tension. Instruments are mounted on the upper part of the panels, control and operating devices in the middle within easy reach, that is, from 3 ft. to 3 ft. 6 in. from the floor, while relays are put on the base. This type of panel is used when the number of units is small, and when the extension of the board does not become too great. It is also used in cases

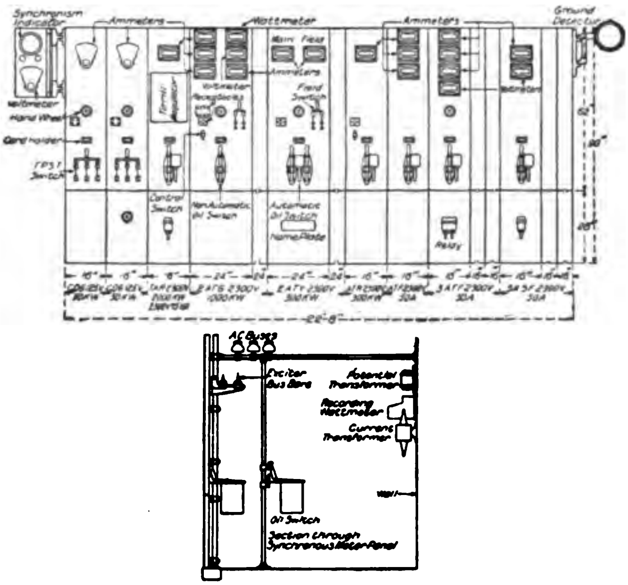


Fig. 202.—Front and End View of a 2300-Volt Alternating-Current Switchboard.

where the space afforded by the control apparatus if removed to another board would be occupied by closely spaced instruments, which would hinder the attendant from readily picking out the required instrument. They are almost always used for hand or wire-rope operated oil switches.

Figs. 202 and 203 show a 2300-volt a.c. switchboard for the average central station. The switchboard contains panels for two exciters, of which one is driven by an induction motor. Both exciters have their own panel. This arrangement has the advantage that each panel with its exciter can be considered

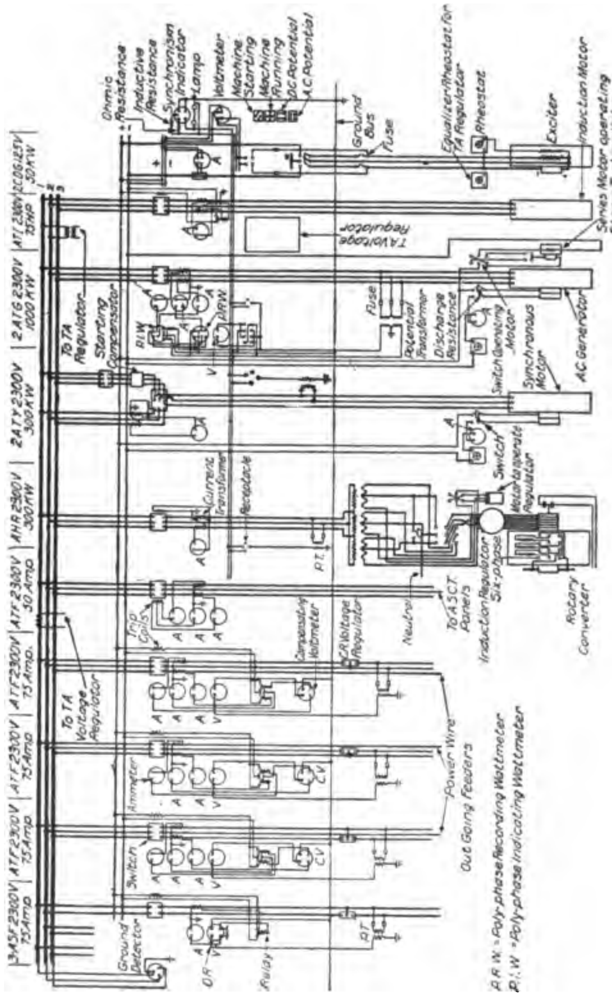


FIG. 208.—Wiring Diagram.

as a unit, and can be disposed of or added as such if any change is made in the equipment. The equipment for each exciter panel is as follows: One ammeter, one field rheostat, with handle, one triple-pole single-throw switch with fuses for 125 volts, and one four-point potential receptacle. These panels are set up at the extreme end of the switchboard so as to distinguish between the low-tension d.c. and the high-tension a.c. sides of the board. The next panel is for the induction motor which drives one of the exciters. This motor is supplied directly from the busbars at 2300 volts which presumes that the other exciter is driven by an engine, or from some other independent source. The equipment of this panel should consist of the following: One ammeter, one triple-pole single-throw automatic oil switch, operated by hand and mounted on the back of the panel, and one inverse time-limit relay. In almost all new plants a Tirrill regulator is installed, which is mounted between generator and exciter, but which may here be placed on the motor panel, as there is sufficient space to receive it. As the regulator is to control two exciters, an equalizer rheostat should be added on one of the exciter panels. The voltmeter for the exciters is mounted on a swinging bracket on the d.c. side of the switchboard.

The next panels in order are the two generator panels, each for 1000 kw., 2300 volts, equipped with the following instruments: Three ammeters (unbalanced load), one polyphase wattmeter, from which is read the load division on the two generators, one field ammeter, which, as previously mentioned, facilitates detection of generator troubles, one voltmeter, to read the voltage of the machine between any two phases, and also the potential of the buses by means of an eight-point receptacle, one four-point synchronizing receptacle with the necessary synchronizing plugs, one double-pole single-throw field switch with discharge clips and resistance, one field rheostat, which, when small, is mounted on the panel and is operated by a handwheel, and when large is placed away from the boards and is operated electrically or by chain; and one triple-pole single-throw non-automatic oil switch. Non-automatic oil switch is recommended for generators, because when synchronizing, if the machines are not exactly in synchronism when they are connected together, or if a short-circuit or over-

load occurs on any feeder, an automatic generator switch is liable to open and shut down the plant. Most a.c. generators are so designed that they can carry a momentary short-circuit without injury. When panels are furnished for turbine driven generators rated at more than 500 kw., a double-pole double-throw engine governor control switch is furnished for controlling the motor of the governor. Two series and shunt transformers are provided for the instruments which are generally mounted on pine supports or on the wall. (See side elevation.) The synchronism indicator with signal lamps is placed on the swinging bracket with the d.c. voltmeter.

When motor-generator sets are used for furnishing either Edison three-wire d.c. service or 500-volt railway or power service the synchronous motor is supplied directly from the main buses. The equipment for the motor consists of a triple-pole single-throw magnetizing oil switch, a starting compensator, and a triple-pole double-throw oil switch. In starting it is supplied with current through the magnetizing switch and compensator, and through the other side of the double-throw oil switch when running. The magnetizing switch and the double-throw switch are interlocked so that the latter is either directly connected to the busbar, in which case the primary switch is open, or to the compensator, in which case the primary switch is closed. Operation is accomplished by two handles so that only one at a time can be in the outer position. In place of a double-throw oil switch two single switches are sometimes used, so that the motor is started through two switches and is maintained through one. In the side elevation there is shown the magnetizing oil-switch mounted on a separate pipe support at the back of the board. The equipment for the synchronous motor panel is one main ammeter, one field ammeter, one field switch with discharge clips and resistance, one rheostat with handwheel, one synchronizing receptacle, and one shunt and two series transformers built into the feeders.

The next panel is that for the synchronous converter. When converters are used for feeding Edison three-wire service it is customary to install a regulator on the a.c. side of the converter in order to be able to control the e.m.f. of the d.c. service. This regulator is usually made motor controlled, and

in such cases a double-pole double-throw switch should be mounted on the panel. Besides this the panel carries one main ammeter, one synchronizing receptacle, one triple-pole single-throw automatic oil switch, and one shunt and two series transformers.

The diagram shows two kinds of a.c. feeders, one three-phase and one single-phase. The former is used for motor power distribution, and the latter for lighting. If three-phase feeders are used to feed lamps as well as motors, the lighting circuit is connected to one phase of the three-phase feeder, and the regulator is inserted in the same phase.

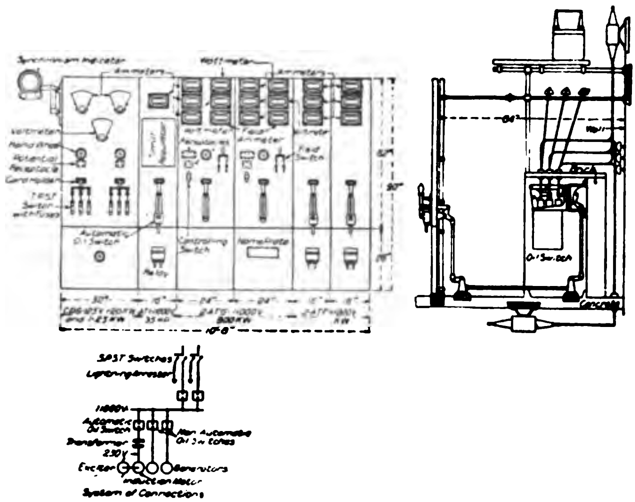


Fig. 204.—High-Tension Switchboard.

The three-phase feeder panel for motors only carries three ammeters, one triple-pole single-throw automatic oil switch and two series transformers. Such panels for both lighting and motor power have in addition a compensating voltmeter, a handwheel or control switch for operation of the regulator, and a shunt transformer.

If single-phase feeders are used for lighting, the equipment should be as follows: One ammeter, one compensating voltmeter, one double-pole single-throw automatic oil switch, one series and one shunt transformer. All feeders used for lighting have inverse time-limit relays. A ground detector is

mounted on a swinging bracket and is connected to the bus-bars. The latter are supported on the pipe framework which holds the panels. As noted above, the series and shunt transformers are mounted on the same framework or on the wall, according to the arrangement of machine cables and feeders. They must never be mounted on the board, however, since they are connected to high-tension wires.

A switchboard for two three-phase 800-kw. 11,000-volt engine-driven generators, one engine-driven exciter, one induction motor with an exciter and two high-tension feeders is shown in Fig. 204. The two exciters are controlled from the same panel, which therefore carries a double equipment. The induction motor circuit and the feeders are each furnished with three single-pole automatic K4 oil switches operated as triple-pole switches. They are mounted in separate cells away from the board. Similar oil switches, but non-automatic, are provided for each generator. All cells should be placed in a row in the same order as their panels. For each overhead feeder there should be a lightning arrester with two disconnecting switches, one to break the line and the other to disconnect the arrester. The diagram shows the connections by simple lines. The side elevation is the same as that for the central station with the exception that single-pole oil switches are used in place of three-pole. The buses are mounted on insulators above the cells, and are quite exposed. This arrangement is not to be recommended for large installations, for with such high voltages, in this case 11,000 volts and large kilowatt rating, separate fireproof compartments should be provided for the buses. The small wooden gallery over the buses serves for mounting the shunt transformers, and for the purpose of operating the disconnecting switches, which for the overhead lines are placed high up out of reach.

Figs. 205 and 206 show a Westinghouse switchboard for the control of two 150-kw., 125-volt exciters, seven 1500-kw., 2200-volt generators, and two banks each of three 1500-kw step-up transformers. The swinging brackets on the left carry three voltmeters and one synchroscope. The next two panels belong to the exciters, and the next seven to the generators, each one controlling two non-automatic type E oil switches to connect the machines to either set of buses. The rest of the equipment

is the same as previously described. The last panels are for the step-up transformer banks, and each carries three ammeters, one power-factor indicator, one polyphase watt-hour meter, and also controls two automatic oil switches with their overload relays. The necessary series and shunt transformers are built into the line. The diagram shows the connections of only one of the generators with one of the transformer banks. All

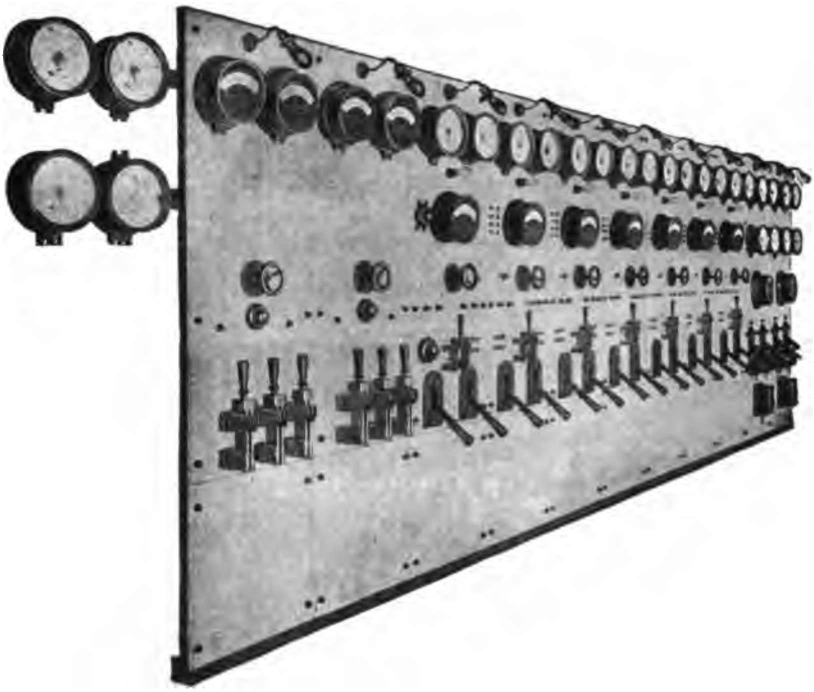


FIG. 205.—1100 to 2500-Volt Alternating-Current Switchboard.

buses, oil switches, and instruments transformers are enclosed in separate fireproof cells and compartments. A voltmeter and frequency indicator are connected to each set of busbars.

A typical arrangement of feeders and generator panels is shown in Fig. 207. The switchboard is set up separated from the oil switches and busbars. In order to indicate to the attendant the functions of the various oil switches controlled and operated from the board, there are mounted on the board next to the control apparatus a set of mimic busbars with con-

nections. The connections to these buses are an exact single line reproduction of the actual arrangement. Small knife-blade switches or white indicating lamps are used in the connections and mimic buses to represent the disconnecting

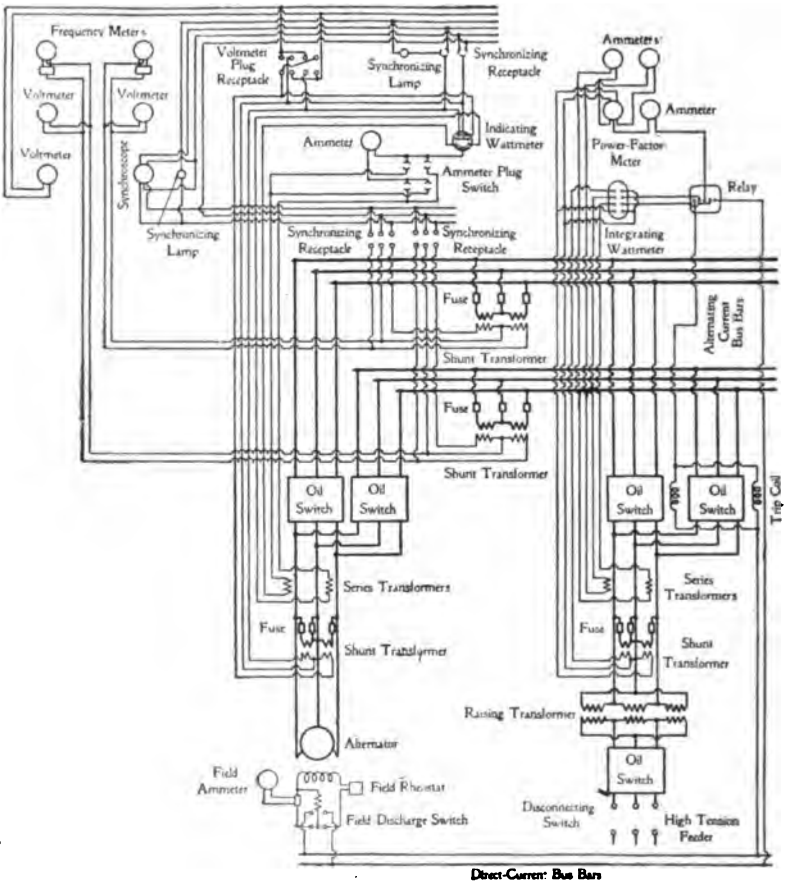


FIG. 206.—Wiring Diagram of Board Shown in Fig. 205.

switches. Whenever a set of disconnecting switches is opened the attendant opens the corresponding knife-blade switch in the mimic arrangement, or an indicating lamp is automatically lighted. This materially reduces the liability of wrong switching. Two signal lamps, one red and one green, are connected to the control apparatus to indicate whether the oil switch is

open or closed, and a name plate with the number of the generator, feeder or transformer bank is placed next to them. The illustrations in Fig. 207 show two parallel copper strips representing two sets of busbars. On the generator panel there are three control switches which operate three oil switches. The generator has one main oil switch and two selector switches,

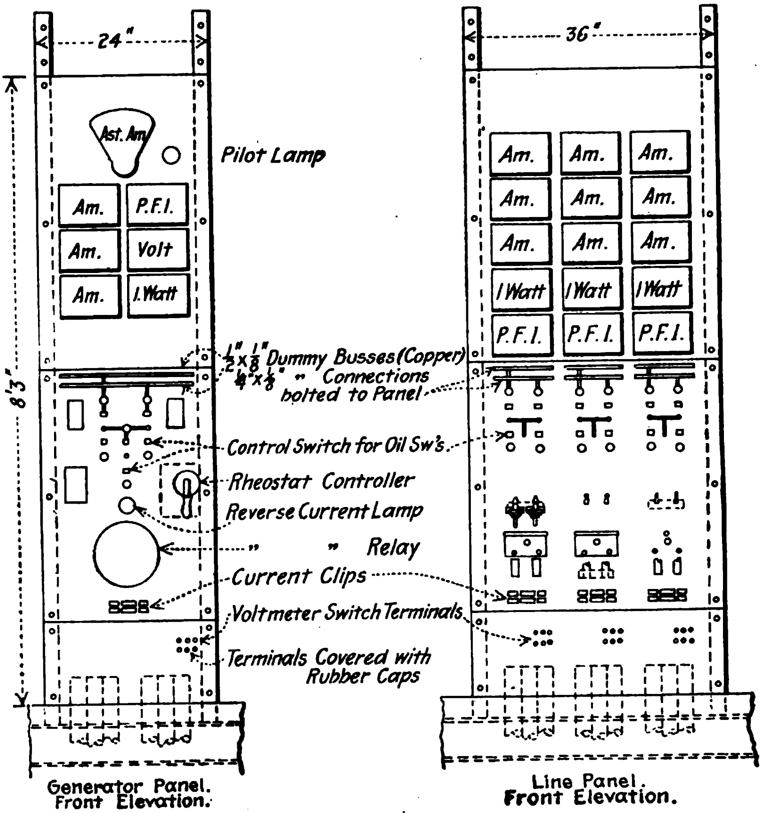


FIG. 207.—Typical Generator and Line Control Panel.

which connect it to either set of busbars. The field rheostat of the generator is motor operated and is controlled from the board. The feeder panel controls three independent sets of feeders, each of which possesses two electrically operated automatic oil switches. The same is true for the transformer panels.

When it is desirable to reduce the length of the switchboard to a minimum all control apparatus (for electrically operated oil switches, field switches, field rheostats, governor control, and motor switches, etc.) are mounted on a bench board. Instruments for the various circuits are arranged so as to enable the attendant easily to pick out which instruments and control apparatus belong together. They may be mounted on an independent panelboard or on the panel which constitutes

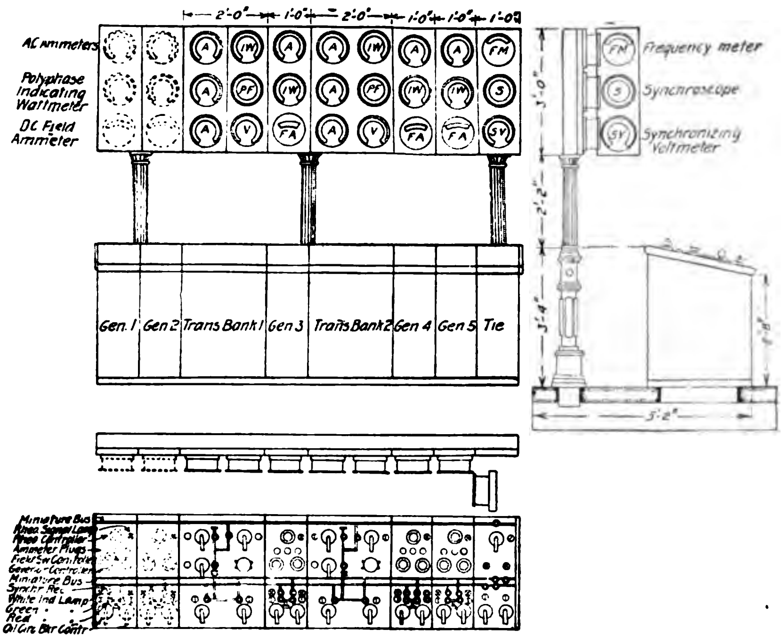


FIG. 208.—Bench Board.

the back of the bench. A panel on the bench itself or on a frame over the bench is also sometimes used. One or more instrument posts might be employed for the same purpose.

Fig. 208 shows a part of a bench board with instrument board for 100,000 volts. The whole board controls nine 2500-kw., 6600-volt generators, two transformer banks of 4000 kw. each, 6600 volts delta to 66,000 volts star, and two 110,000-volt feeders. When installed complete the board will control the entire station rated at 50,000 kw. On

the bench there are mounted the control apparatus for rheostats, field switches, governor control, and the oil switches for the generators and transformer banks. The plug switches for the synchroscope, ammeter, signal lamps, mimic buses and connections are also carried on the bench. The instrument panel is set up above the bench on a cast iron

FIG. 211.—Fifty-Cycle Alternating and Direct-Current Controlling and Instrument Board.

frame so that the attendant can see between the bottom of the panel and the top of the bench, and so obtain a full view of the station. The three station instruments on the swinging bracket on the right side can be brought into any desired position with respect to the board, so that the attendant can see them from any position. The supports for the instrument panel also serve as a railing around the gallery. The front of the panel faces

the inside of the gallery. The instruments on the vertical panel correspond in position to their control apparatus on the bench.

Other examples of this type of switchboards are bench boards for 11,000 volts, set up by the Westinghouse Company in the Williamsburg power house of the Brooklyn Heights Company. A separate bench with instrument board is furnished for the generator control. Opposite the bench is placed a double switchboard for the control of all other high-tension machines and feeders. The space between the opposite panels in the feederboard is closed by two doors, one at each end. The front and rear board carry both instruments and control apparatus (front board), and also the necessary relays (rear board). The d.c. panels with the exciter, battery, station lighting and motor panels are mounted independent of the high-tension switchboard. Symmetry and artistic appearance are observed throughout and by compact arrangement a minimum amount of space for controlling the entire large plant is taken up.

Fig. 211 shows a combination of a bench and instrument panel with a panelboard in back of them. In the illustration the panelboard is not shown. The space between the boards is closed by two doors. A cast-iron framework holds the panels together, and the whole forms an independent closed compartment. The two boards at the extreme right and left control the exciters. Relays, controls for electrically operated field switches, wattmeters, switches for station lighting and watt-hour meters are carried on the rear panel. The bench board and instrument panel at the front carry the control apparatus and instruments for the generators, feeders and transformer banks. When Tirrill regulators are used they are mounted on the vertical boards on either side of the bench. On the wall in front of the bench there are sometimes mounted the control apparatus for electrically operated rheostats and governor controls, and for the electrically operated gates for the intake water for the power house. The separate parts of the bench and panels are held together by gas piping and clamps. The exciter buses and gas pipes connecting opposite panels should be mounted so that one may safely walk underneath them. Similarly the mounting of the exciter field rheo-

stats and the copper connections to the exciter buses must be such that safe passage is possible.

Instead of mounting the instruments on vertical panels they may be placed on posts with the corresponding control apparatus assembled on a bench or pedestal. Two of these instrument posts with a different number of symmetrically ar-

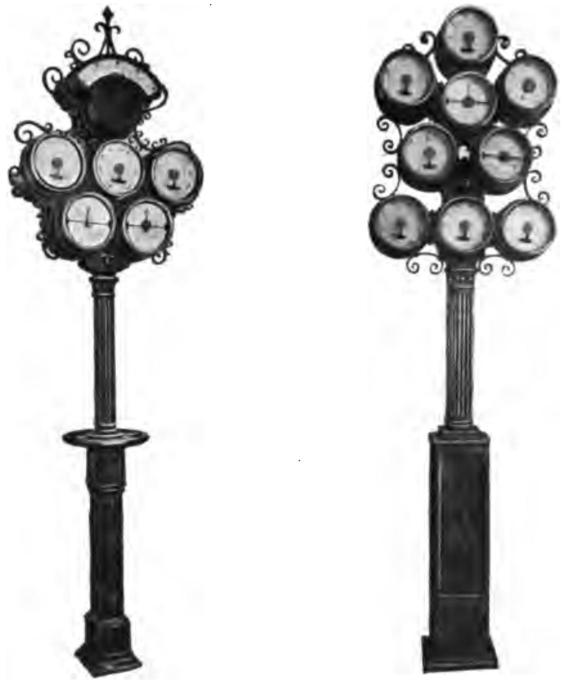


Fig. 212—Instrument Posts.

ranged instruments are shown in Fig. 212. They are often used as railing supports when they are placed on the edge of the gallery. Their upper parts are generally movable so that they can be turned by means of a handwheel at their base. Some of them carry a set of receptacles with plug switches on the base, for testing the instruments. All instrument wires are carried inside the posts.

Fig. 213 shows two pedestals with control apparatus, which constitute independent units with the corresponding instru-

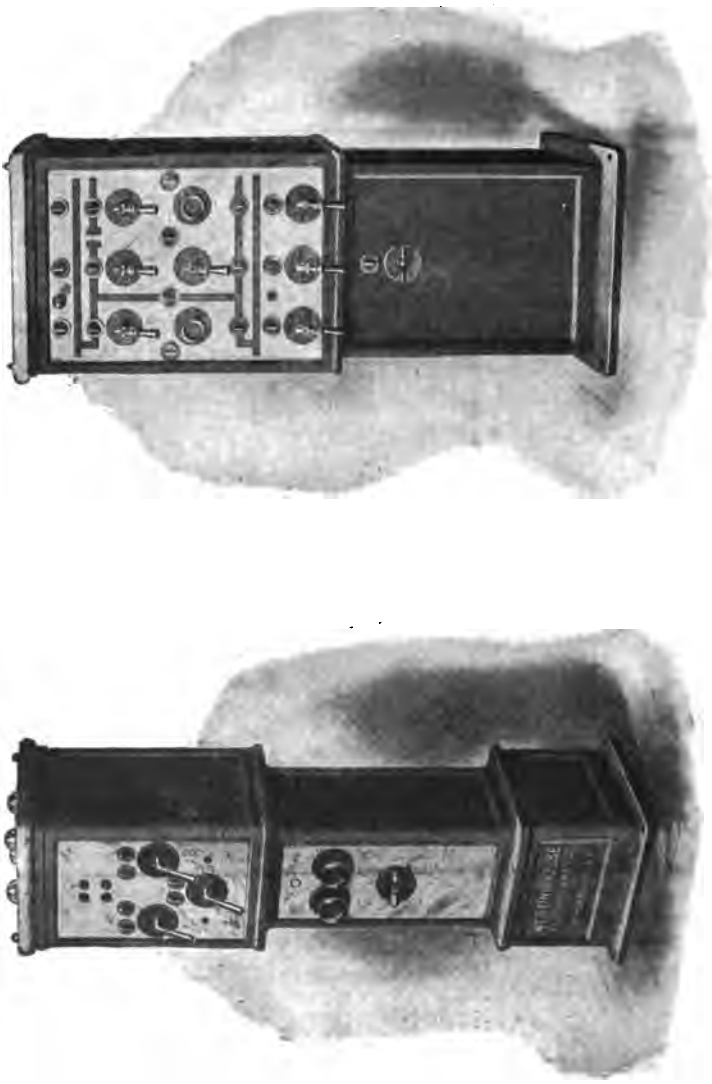


FIG. 213.—Control Pedestals.

ment posts. One controls a generator, and the other a bank of three transformers. The control of the former is for oil switch, rheostat, governor-control and field switch. Hand-wheels for chain operated rheostats are also sometimes mounted on them. The frame is of cast iron and the panels of blue Vermont marble. Control wires are led through the open base to the interior, and small doors are provided for inspection of the various connections. The pedestals are set up in a row in front of the instrument posts so that the attendant can overlook the entire station. On the second pedestal are mounted the mimic buses and indicating lamps.

CHAPTER XXII

CELLS AND COMPARTMENTS

As has been previously stated, high-tension apparatus and busbars must be guarded by fireproof insulating barriers. The purpose of such barriers, cells or compartments is to protect apparatus, etc., against destruction by fire which may be caused by sparks, arcing or short-circuit, and at the same time to protect attendants from accidental contact with high-tension parts.

Two kinds of apparatus requiring such protection must be distinguished. The first includes appliances whose action is accompanied by sparking or arcs, the duration of which is determined by the voltage and value of energy back of them, as well as by the construction and material of the instruments. Lightning arresters, disconnecting switches, fuses, etc., will serve as examples. Busbars, transformers, oil switches, etc., are appliances which will produce arcing accidentally. The causes for this may be either careless handling, damaged insulation, too high tension, improper spacing, or short-circuit. Arcing is detrimental not only to the apparatus itself, but also to adjacent machinery. In this kind of apparatus the destructive effect is mainly dependent upon the energy back of the arc.

In order to reduce the dangers mentioned above to a minimum the following points should be observed:

1. The system of connections should be laid out as simply as the control of the station will admit.

2. The connections from generators to transmission lines should follow the shortest and most direct path.

3. Apparatus of the first group should always be placed in compartments when under high or extra high tension, while that of the second group at high and extra high tension and large current, and those for smaller current, which are easily accessible, must also be enclosed in fireproof compartments.

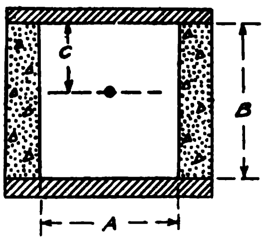
4. High-tension parts must be separated from each other, and from inferior insulation, by the greatest possible distance.

The choice of material for compartments is somewhat restricted, for no material combining the qualities of cheapness, fireproofing, strength and perfect insulation is at present available. Although the material most often used may possess some of the above qualities it generally lacks the property of perfect insulation. High-tension parts must therefore be widely separated on account of the danger of grounding, and this in turn calls for considerable space. Concrete or brick 4 in. thick is most generally used for these compartments. The horizontal divisions are made of soapstone or slate. Glass, porcelain and asbestos are less in use on account of their fragility and poor insulation respectively. For very high tensions, busbars and bus wires are mounted bare. They should therefore be placed near the ceiling in order to prevent accidental short-circuit through falling objects and contact of the attendants.

BUSBAR COMPARTMENTS.

Dimensions of 22,000, 33,000, 45,000, 66,000-Volt Compartment are based on the assumption that Bus Wires are fastened to Insulator by means of Tarred Rope. If Metal Fastenings are used or Metal Caps are required for Disk-Switches or other purposes, the Dimensions should be increased so as to obtain the same Distance between Compartment and nearest Live Metal.

Standard size of Brick, 8¼″×4¼″×2¼″.



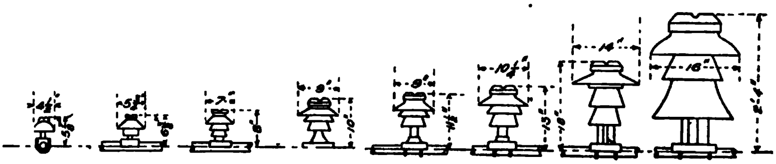
Volts.	Bus.	A.	B.	C.
5,000 to 15,000	One—2″×¼″ bar	13″	12⅜″	5¼″
5,000 to 15,000	Two—2″×¼″ bar	13″	12⅜″	4¾″
5,000 to 15,000	One—3″×¼″ bar	13″	12⅜″	5¼″
5,000 to 15,000	Two—3″×¼″ bar	13″	12⅜″	4¾″
5,000 to 15,000	2″ or 3″×¼″ bar	12″	12⅜″ or 14½″	4″ or 5½″
22,000	Wire	15″	16½″	8½″
33,000	"	18″	19¾″	9¾″
45,000	"	2′ 1″	2′ 2″	13″
66,000	"	3′ 0″	3′ 1″	18″
100,000	"	4′ 8″	4′ 8″	2′ 4″

Where such mounting is not feasible, or where the connections are too complicated, the busbars are built in compartments. These may be entirely closed, having openings or may be open on one side, in which case they would con-

sist of a vertical wall with horizontal barriers between the buses.

The figure and table on page 279 show a typical cross section of one of these compartments, with the dimensions for different voltages for horizontal or vertical mounting of busbars and the use of bus wire. All these dimensions are for the same make of insulators (General Electric), which are built into the horizontal base. The figure and table below show these insulators for different voltages mounted on piping with the distances from center to center and to ground. With any change in dimensions in other makes for the same voltages the corresponding dimensions of the compartments must be changed.

BUS WIRE SUPPORTS.



1 2 3 4 5 6 7 8

Number.	E.M.F.	Spacing.	Ground Distance.	Number.	E.M.F.	Spacing.	Ground Distance.
	Volts.	Inches.	Inches.		Volts.	Inches.	Inches.
1	6,600	8	6	5	33,000	18	10 to 12
2	15,000	10	7	6	45,000	25	13
3	22,000	12	8 to 10	7	60,000	36	19
4	33,000	18	10	8	100,000	56	30

NOTE.—Ground distance (usually) $= \frac{\text{Wire spacing}}{2} + 1$ in.

Spacing of series transformers (self-cooled):

600 volts	1 in. clear	6,600 volts	3 in. clear
2,300 "	1.5 " "	13,200 "	5 " "

In Fig. 214 there are shown the cross sections of compartments for 6600 volts and medium rating, and 6600 volts at greater rating. This construction with insulators in the sides of the compartment is good up to 15,000 volts, but for higher tension, openings must be left for the connection. In Fig. 215 are shown a number of different arrangements of busbar compartments, in connection with the oil switch cells. (Form H3) for 13,200-volt plants. Note the mounting of the dis-

connecting switches between the barriers which are shut in by doors in the front. In the left-hand installation the lower stud of the disconnecting switch is connected to the buses. This arrangement is not to be recommended because when the disconnecting switch is open, which presumes that the oil switch is also open, the handle is alive, although it should be dead in this position. The connections in this case are made of copper

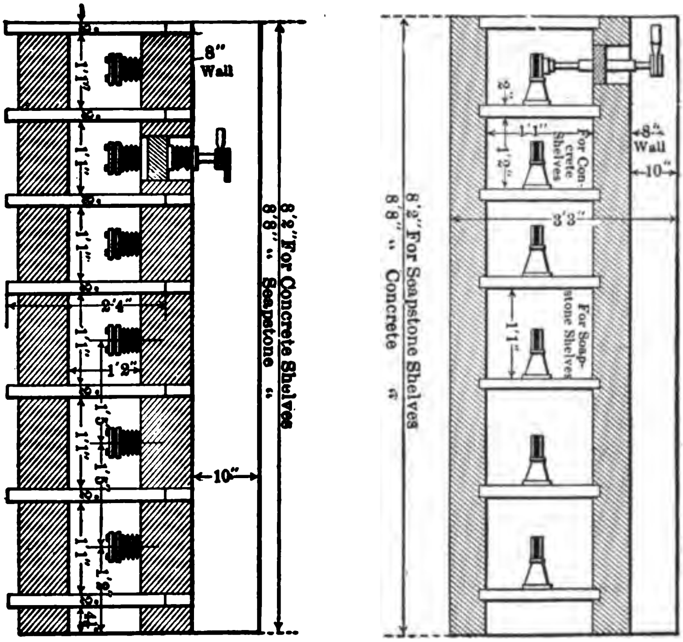


FIG. 214.—Bus Compartments for 6600 Volts Medium and High Ratings.

rods or tubing, but might just as well be made with copper wires. The space over the compartments is sometimes utilized for shunt transformer compartments. The busbar supports should be set up near the openings for the connections, or if special openings in the back of the compartment are provided, near these, so as to admit of inspection. They are generally spaced about 4 ft. apart.

Fig. 216 shows a section, and Fig. 217 an elevation of oil switch cells (form H3), and busbar and instrument compartments for a 6600-volt plant, whose control panels were shown in Fig. 207. It will be remembered that in that arrangement

the generator was provided with one main and two selector oil switches, and the feeders and transformers with two selector switches each. The two oil switches of Fig. 216 mounted back to back are the two feeder selector switches mentioned above. The two inner poles are connected together, and the feeders run out from this common connection. The feeders are run on

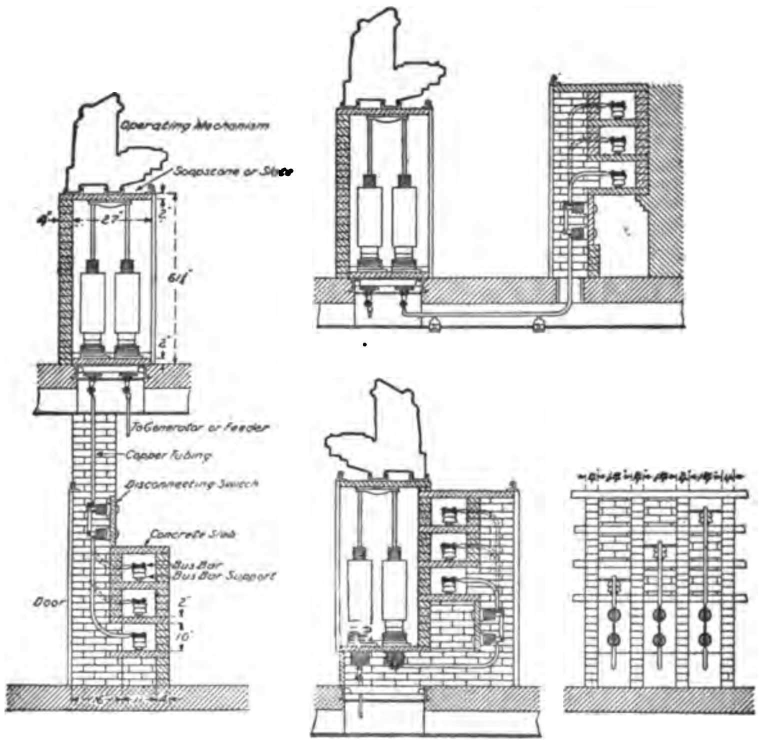


FIG. 215.—Bus Compartments for 13,200 Volts in Connection with Motor Operated Oil Switches.

the basement ceiling down the wall, where series transformers are built into the two outer legs. (See Fig. 218.) On the outer side of the transformers are inserted the disconnecting switches which join the transmission line to the station apparatus. The entire equipment on the wall is enclosed in brick compartments. The cables are conducted through the walls and floors in bushings, and the three-conductor cables are joined to the three single feeders by end bells.

In Figs. 219 and 220 the arrangements of oil-switch cells and bus and instrument compartments of the Williamsburg Power Station of the Brooklyn Heights Railway Company are shown,

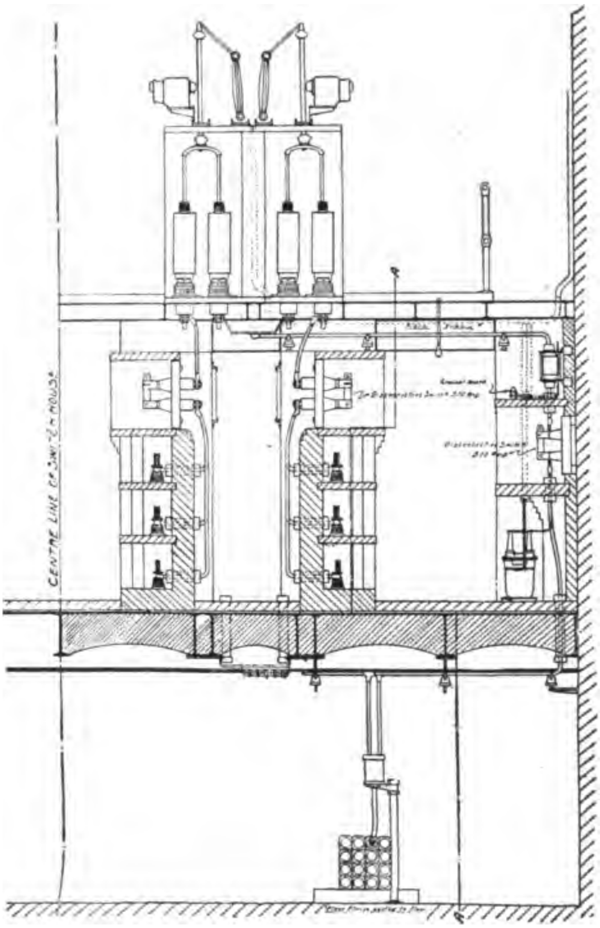


FIG. 216.—Cross Section of Bus and Instrument Compartments of the Boston Edison Company Power House.

the main switchboard of which is shown in Figs. 209 and 210. It is a four-story arrangement with the generator and feeder group switches on the fourth mezzanine, the busbar compartments on the third and the feeder, motor, and tie oil switches on the second. The oil switches are type C Westinghouse, with

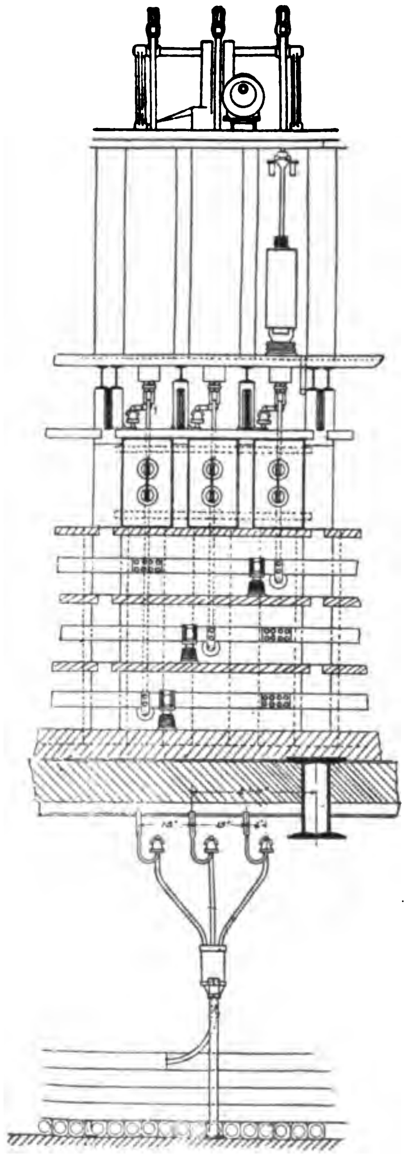


Fig. 217.—Elevation of Bus Compartments of the Boston Edison Company Power House.

terminals on the back of the cell. The series transformers on the fourth mezzanine are set up under a false floor, and those on the second in compartments on the back of the oil switches. The shunt transformers for the generators in Fig. 219 are set up in compartments on the wall of the third mezzanine, and those for the feeder group switches on the fourth mezzanine in

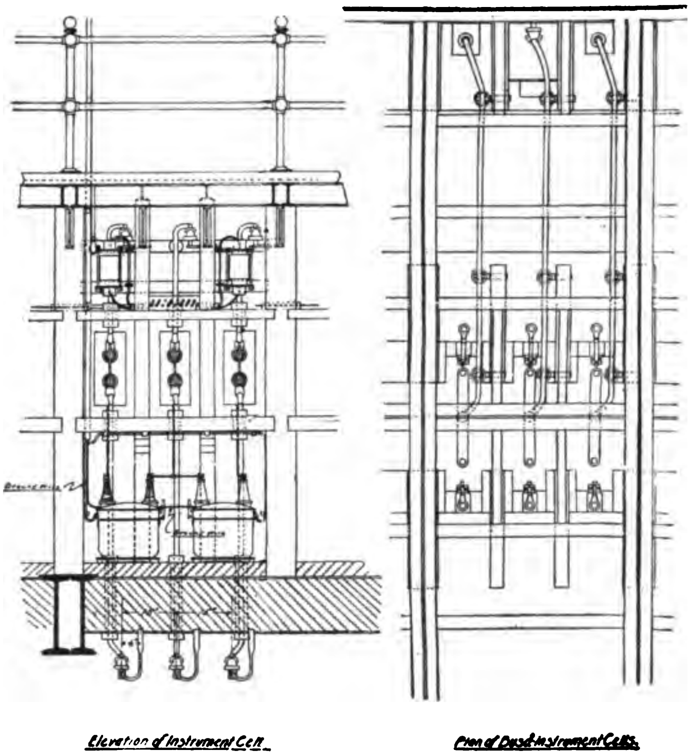


FIG. 218.—Plan and Elevation of Bus and Instrument Compartments of the Boston Edison Company Power House.

cells similar to oil-switch cells. Primary fuses are mounted separately, and are easily disconnected from the shunt transformers. Disconnecting switches are also provided between the shunt transformers and the high-tension leads. All disconnecting switches are set up in compartments, and are operated through rectangular openings on the front side. Notice that the generator and motor cables, as well as the potential and

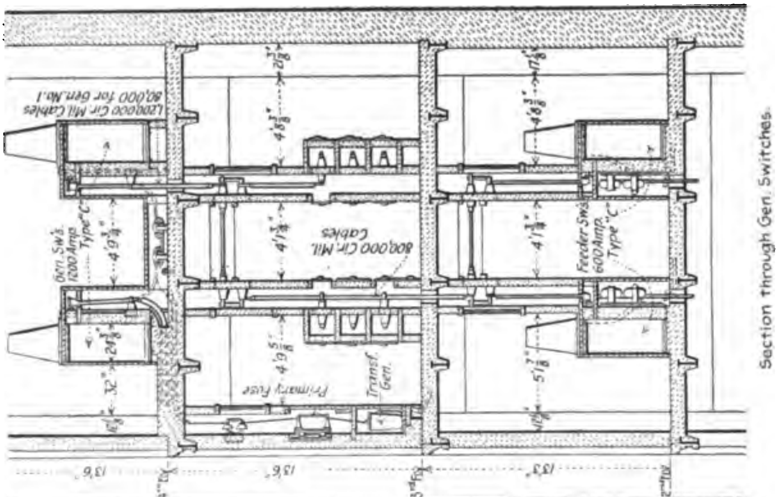


FIG. 220.—Cross Section Through Electric Galleries of Williamsburg Power House.

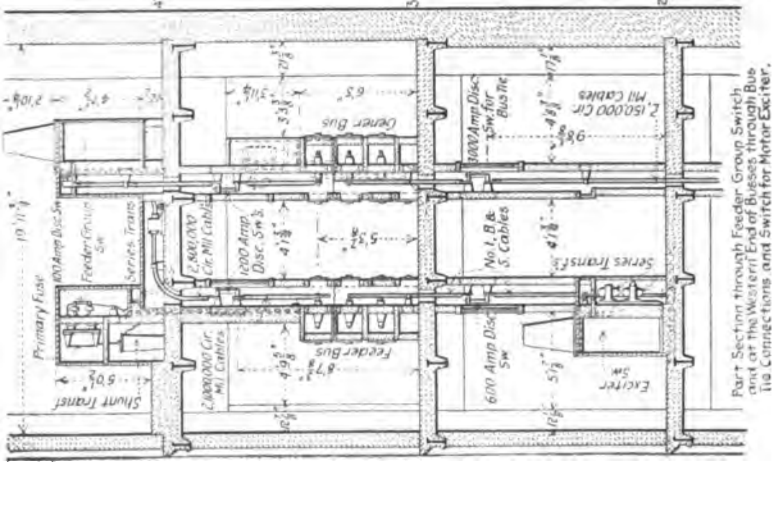


FIG. 219.—Cross Section Through Electric Galleries of Williamsburg Power House.

instrument wires are laid in conduits built into the concrete floors. All of the galleries are entirely separated from the engine room, with the exception of the third, which has a glass enclosed platform in front of the main switchboard facing the engine-room floor.

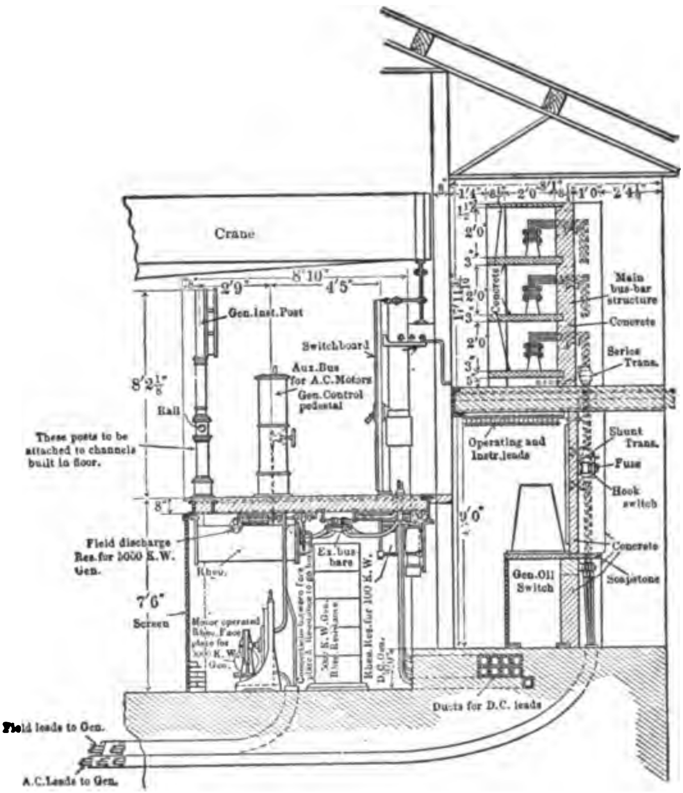


FIG. 221.—Cross Section Through Electric Galleries of a Large Station for 2200 Volts.

Fig. 221 is an arrangement of cells for a 2200-volt plant of large capacity. The arrangement is divided into two parts, one control operating division situated in the engine room, and the other high-tension part in a separate room outside the engine room. Part of the first division is on the engine-room floor, and the other part in the gallery. That on the floor is screened

off and carries the field rheostats, their operating motors and the exciter buses. In the gallery are mounted the instrument posts, control pedestals, and the switchboard for controlling the exciters, motors, etc. The second division is also composed of a basement and gallery. On the part on the floor all the oil switches are found, and the busbar compartments are situated in the gallery. The connections are made by copper bars. The bus compartments are open on the front side and the overhanging horizontal divisions are supported by concrete pillars.

It is recommended by some engineers that all instruments and apparatus requiring special cells and compartments on the different galleries be set up outside the station so as to do away with costly construction, at the same time preserving the requisite conditions for safety to station and attendants. Their argument is, that as long as overhead transmission lines are left unprotected by barriers or special enclosures, even though they carry the same e.m.f. as the station appliances, this station apparatus may just as well be set up in similar manner, provided it is properly spaced and so arranged that accidental contact is made impossible. Such devices may therefore be installed overhead like transmission lines, with proper protection against snow and rain, etc.

It will be noted that a more or less arbitrary distinction has been made throughout this treatise between high and extra high tensions. Extra high or highest voltages have been taken as those over 33,000 volts.

CHAPTER XXIII

WALL OUTLETS

Bringing high-tension lines into stations necessitates carefully constructed wall inlets, which will successfully resist weather and electrical influences. When designing the building the installation of these inlets must be taken into consideration and proper provision for them must be made, for otherwise their location relative to the steel work and the position of the machines might be undesirable. It is impossible to state any hard and fast rules covering all cases, for local conditions generally determine the ways and means for solution. Mr. C. E Skinner recommends that the following points be looked into before a definite arrangement is decided upon:*

1. Voltage of the transmission circuit.
2. The climate in which the plant is to be operated.
3. The size and insulation of the high-tension conductor.
4. The kind and height of building used.
5. The conditions of approach to the building and the location of the apparatus in the building to which the high-tension line is connected.

After these points have been investigated, the following requirements must be met by a proper form of inlet.

1. It must maintain proper insulation of the circuit under normal as well as abnormal atmospheric and electric influences in and outside the conductors.

2. Snow, rain, cold air and dust must be prevented from entering, since they weaken the insulation at the point of entrance, which may result in damaging the contents of the building.

3. The end strains of the line must be taken up, and must not be transmitted to the inlets. Special line poles and

* "Methods of Bringing High-Tension Conductors into Buildings." C. E. Skinner. Proc. A. I. E. E., July 1. 1903.

supports with insulators outside and inside the station take up this strain and serve to center the lines in the inlet openings.

4. The construction must be reliable, simple and cheap.

The simplest form of inlet is a hole in the wall of sufficient diameter to allow enough open space about the wire to prevent

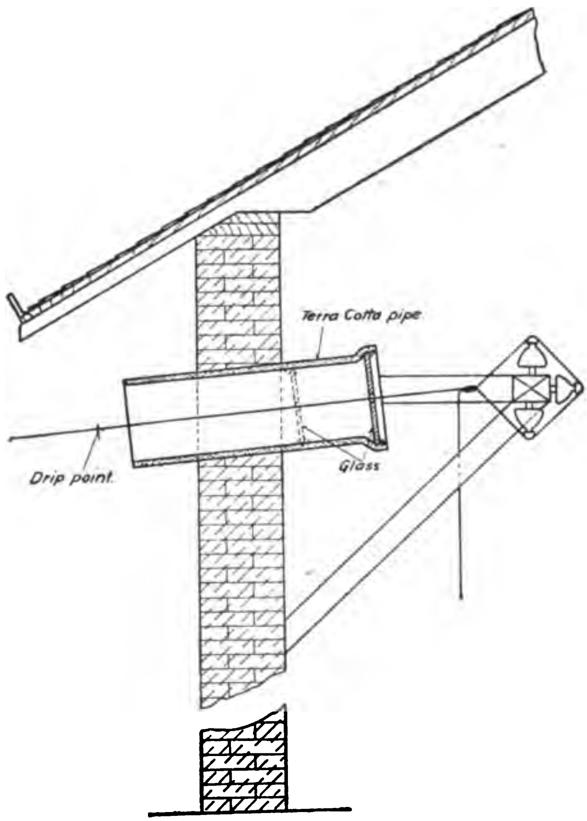


Fig. 222.—Wall Outlet with a Terra Cotta Pipe.

any possibility of an arc striking across to the walls or surrounding material. The opening is protected against snow, rain, etc., by a terra cotta pipe sloping outward or by sufficient extension of the roof above. Special steel or wooden hoods, or a gallery built around the opening on the outside of the wall are also sometimes used. The line must be held in the center of

the hole or tube to keep it away from the wall or side of the tube, which are considered as ground. The above arrangement is applicable only for medium tensions up to 15,000 volts in dry and warm climates. For 15,000 volts or less the terra cotta pipe is closed on the station side by one or two glass disks with holes. (See Fig. 222.) In this case the pipe must be of a

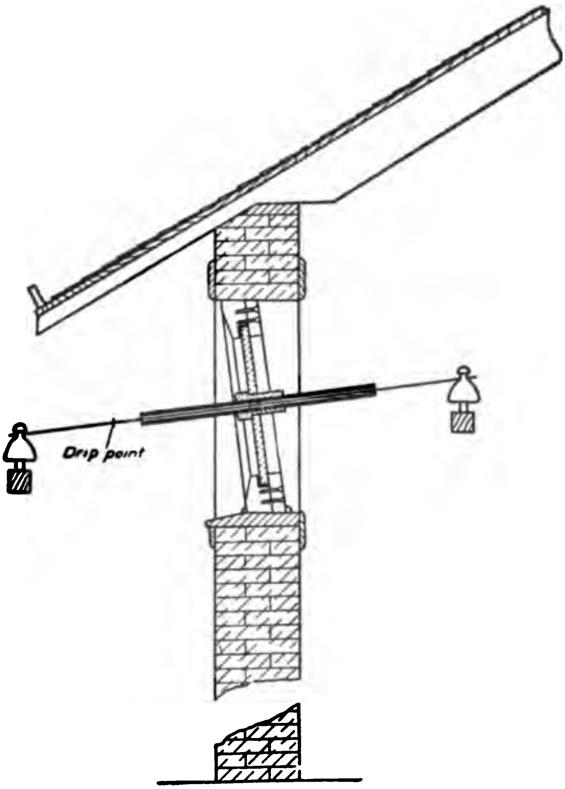


Fig. 223.—Wall Outlet with a Slab of Insulation Material and Insulating Tube.

diameter which will allow a sufficient surface insulation of the glass plate against leakage, which might otherwise produce grounding. The insulation at the inlet should be somewhat greater than that of the line itself, as otherwise any electric disturbance might cause an arc at this point which could prove disastrous to the building. The main disadvantages of the

arrangement are, fragility of the glass plates, opportunity for accumulation of dust and moisture, reducing the surface insulation of the plates, access for birds and insects in the outer part of the pipe, and above all, the large diameter of the pipe which is necessary for higher voltages and unfavorable conditions.

A method used for high voltages up to 60,000 volts is shown in Fig. 223. A long insulating glass or porcelain tube of small diameter and very heavy wall is placed over the wire and passed through a slab of insulation set in the wall of the building, the whole being protected from driving rain by an extension of the roof or special hood. Both tube and slab should be of fireproof material. The chief difficulty is in secur-

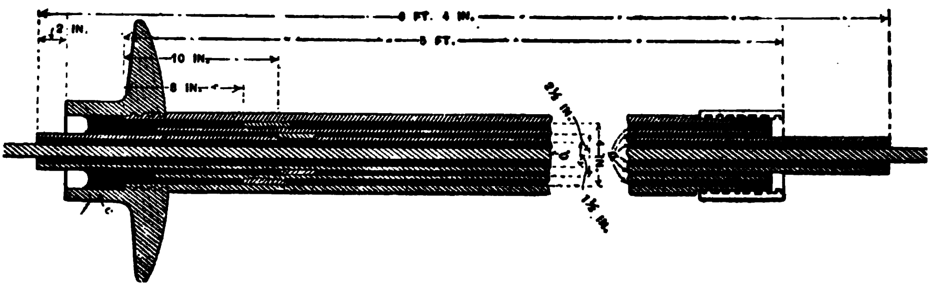


FIG. 224.—Wall Bushings for 44,000 Volts of the Telluride Power Company.

ing the proper insulating tubes. Glass and porcelain are electrically the best materials for the purpose, but on account of their lack of mechanical strength even the difference between out-of-door temperature and that inside will weaken them. For this reason the end strain must be taken up outside the building by a suitable guide pole. Sometimes two or three glass plates are used and the tube is cemented through them. In other cases the glass tube is fitted into a wooden tube of paraffined wood and this is set into wooden panels. This arrangement is sometimes used in iron construction. As a rule, however, it is not advisable to make use of combustible material near the line.

If the building is too low and the line wires must be carried at a considerable elevation in the immediate neighborhood of the building, or the multigap lightning arresters require a high

space for setting up, a tower construction may be necessary for the entrance of the line. Otherwise the inlet is the same as

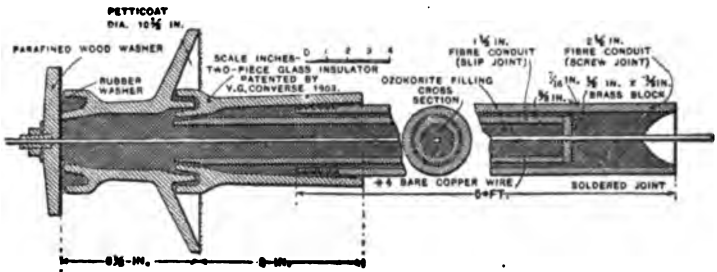


FIG. 225.—Wall Bushings of the Telluride Power Company.

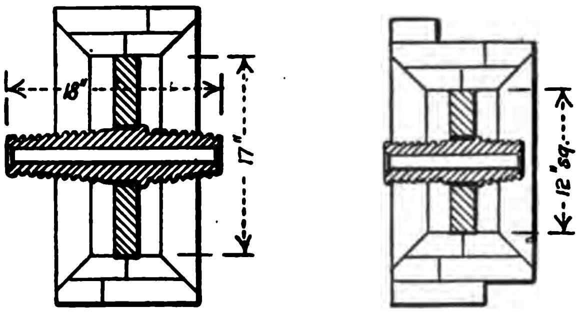


FIG. 226.—Wall Insulators for 11,000 Volts (R. Thomas Company).

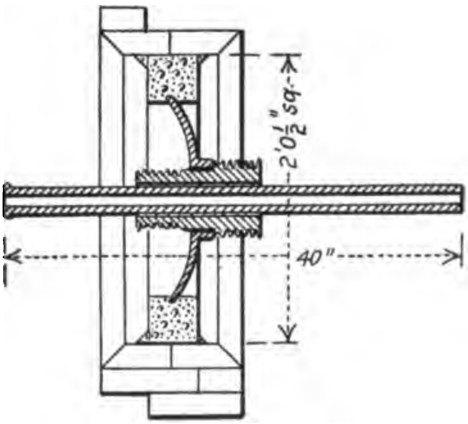
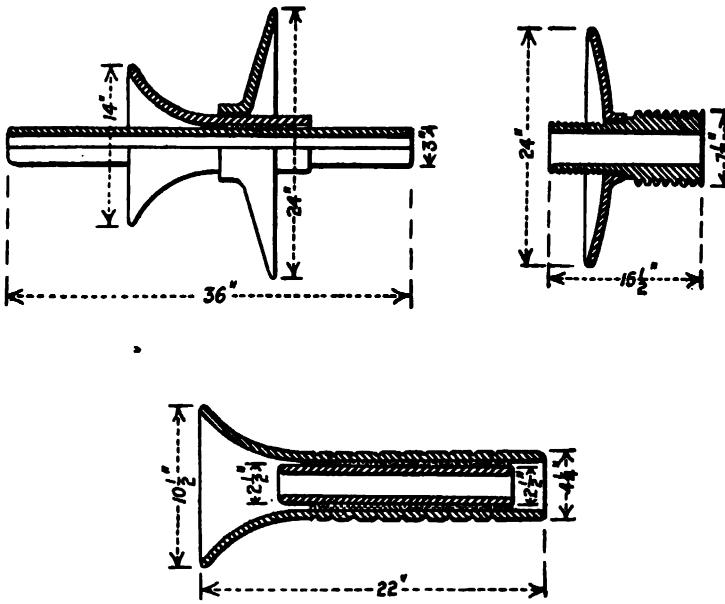


FIG. 227.—Wall Insulators for 44,000 Volts (R. Thomas Company).

through the side of the building. There are any number of different forms of inlets in use, as every plant and manufactur-

ing concern devise their own appliances so as to suit local conditions.

Fig. 224 shows a wall bushing used by the Telluride Power Company, of Provo, Utah, for 44,000-volt lines. It consists of a set of concentric fiber conduit tubes, the spaces between which are filled with ozokerite while the ends are sealed for short consecutive spaces with chatterton compound, minerallac, and a



FIGS. 228-230.—Wall Insulators of R. Thomas Company for Different Voltages.

very brittle asphaltum compound, to prevent the ozokerite from oozing out. The outer end is covered with a porcelain sleeve, and the whole is fitted into a sewer pipe in the wall. It is protected against weathering by a steel hood. These hoods were found to be too expensive and cumbersome and in severe storms they were torn away together with lines and parts of the building. It therefore became desirable to obtain some other design of bushing of which one end might be directly exposed to the weather, thus doing away with the necessity of a hood pro-

tection, and that might be adapted to the walls and as well as to the roofs of the buildings, and might be of such insulating strength that even a building of the cheapest sheet-iron construction might be used without danger from break-down by puncture. And finally, the cost of material and labor was to be less than for the devices previously used. The bushing in Fig. 225 was found to comply with all these requirements. It consists of a porcelain petticoat and a glass insulator with a fiber conduit which together constitute the mantle. A second fiber conduit cylinder is placed inside the mantle. The spaces

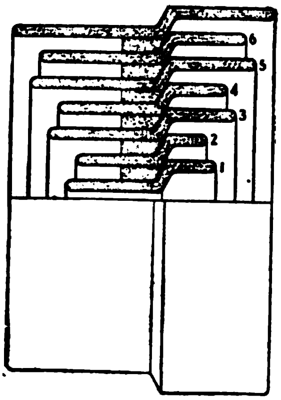


Fig. 231.—Wall Insulator (Locke Manufacturing Company).

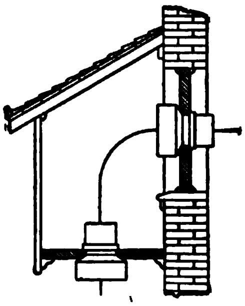


Fig. 232.—Location of Wall Insulators.

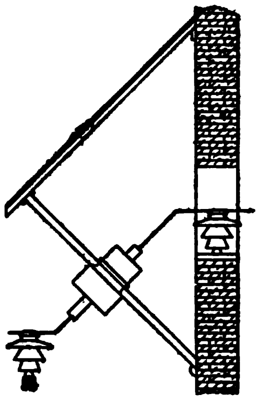


Fig. 233.—Location of Wall Insulators.

are filled out with ozokerite and in the center is laid the bare No. 4 B. and S. copper wire.

Fig. 226 shows a wall insulator for 11,000 volts manufactured by R. Thomas & Sons Co. It is made of a porcelain bushing cemented into a soapstone plate which is fitted into the opening in the wall.

Fig. 227 shows a 44,000-volt insulator of the same make. A long porcelain tube is cemented into a shorter porcelain bushing which sits in a tray-shaped plate fitted into the wall opening. The surface insulation of the bushings must be large enough to prevent leakage.

A number of other bushings are shown in Figs. 228, 229, and 230.

The Locke Insulator Manufacturing Company produces a bushing consisting of concentric porcelain rings, cemented together, the number of rings depending upon the voltage. The bushing and settings are shown in Figs. 231, 232, and 233. In Fig. 232 the bushing is set into a marble, glass, slate or

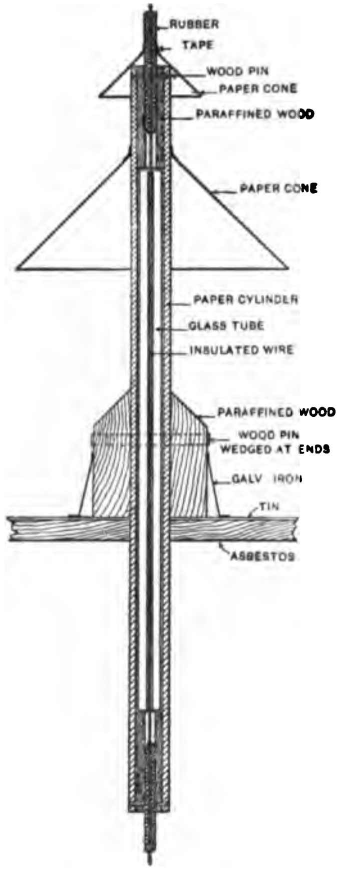


Fig. 234.—Section Through 50,000-Volt Roof Insulator.

thoroughly varnished wood panel, whose diameter is twice that of the outside bushing diameter. In Fig. 233 a second insulator tube is fitted into the bushing. The plate in Fig. 232 may be inclined outward so that the special hood can be omitted.

It sometimes becomes necessary to bring the transmission

line in through the roof, in which case extra precautions must be taken in order to prevent the entrance of moisture. A bushing made for this purpose is shown in Fig. 234. The outside line is carried on the roof by specially built supports.

Where conditions admit it is always best to bring the lines in on the gable end, as on the other ends ice and snow are apt to collect and damage the bushings. Drip points should be fastened on the line near the bushings, and extra guide poles should take up the end strain, so as to keep it away from the bushings or wall. The several feeder inlets should be placed far enough apart to secure adequate fire protection and easy orientation.

CHAPTER XXIV

CENTRAL STATIONS

In distribution systems exceeding a certain size, the use of a single d.c. central station is uneconomical. The reasons for this were stated in Chapters X and XIII. With such systems either one of two methods is followed. The system may either be divided into independent districts, each with its own isolated d.c. plant, or the power generation may be concentrated in one large high-tension a.c. station and fed to substations where it is converted to low-tension alternating or direct current. The choice is determined by local conditions, but in the majority of cases the latter method is adopted.

The advantages of a high-tension a.c. central station regardless of the kind of load may be summed up as follows: The units are of higher rating than those for d.c., so that a greater efficiency is obtainable. Maintenance expenses are lower and when repairs must be made these may be accomplished with greater safety and reliability and at smaller cost. A large saving in operating expenses is also possible since a greater expenditure for labor saving appliances, such as for coal conveying and cinder removing apparatus, may be allowed. The high tension of the system makes it possible to locate the station outside of town limits, so that a greater number of suitable and cheap building sites is available. If isolated d.c. stations are employed to feed a common system, they are subjected to great load variations and therefore operate at low efficiency. By using a single a.c. station, on the other hand, the load variations can be more economically dealt with, and at the same time the cost of reserves is smaller and the managing of the system is simpler and more efficient. The cost of the high and low-tension feeders with their substations is somewhat higher than that for the low-tension feeders of the d.c. isolated stations.

The location of an a.c. station is governed by the same con-

siderations that were found to apply to d.c. plants, with the exception that not so much attention is paid to the location with respect to the load center. The main points to be investigated are as follows:

1. Accessibility, (a) for delivery of coal and removal of cinders; (b) for delivery of heavy machinery; (c) for connections to mains; (d) for officials and workmen.

2. Proximity of water for condensing and boiler feeding.

3. Stability of foundations. If an artificial pile or concrete foundation must be made the initial cost is materially increased.

4. Isolation to secure freedom from causing nuisance by noise, vibration, smoke, dirt, fuel, carting, etc.

5. Facility of extension, which includes the possibility of purchasing adjacent ground for future extensions.

With water power stations, which usually generate high-tension e.m.f. for transmission, the choice of building site is determined by the topography which must be such as to give inlet and exit of water with minimum loss of head, the shortest feasible penstock and the greatest security from variation of head. It must also afford security from floods, possibility for extensions and easy access for overhead lines.

In any large up-to-date installation, a great number of automatic appliances will be found. From boiler room to feeders, the control and handling of large outputs implies the use of labor saving devices to cut down operating expenses whenever possible without impairing the efficiency of the service. In small or medium size stations, however, it is not always an easy matter to determine to what extent the installation of such appliances may be depended upon to give economical results. Their cost in such cases may be out of proportion to the total cost of the plant, so that the saving in operating expenses which they afford will not be actual gain. In very large plants the appliances of this sort will include circuit breakers and oil switches, potential regulators, boosters and batteries, motor-operated circulation pumps, feed water regulators, as well as coal conveyers and cinder removal appliances. Another class of devices serves to indicate the conditions existing in the station apparatus. Signal lamps, for instance, are used to show whether the oil switches are open or closed, which of the ex-

citers is in service, or what set of busbars or feeders is in circuit. In the same way automatic tell-tales serve to attract the attention of the operator to the temperature of the transformers or to the height of the water level in the boilers. When an overload switch opens, that fact is announced in the same way. Automatic steam engine cut-offs and speed limiting devices are important protective appliances. When it is desired to start or stop an engine, generator, exciter, etc., communication between switchboard attendant and boiler engine room is facilitated by whistles, gongs, telephones, speaking tubes and illuminated letter signs. Sluice gates, engine and turbine governors, steam and water inlet valves as well as field rheostats and generator field switches, can be operated electrically from the switchboard.

In alternating-direct current systems, the cost of substations and feeders is an item of considerable importance. Under the discussion of d.c. plants it was pointed out that an increase in the service voltage materially reduces the expense for the copper transmission lines. This applies to an even greater extent to a.c.-d.c. systems such as traction systems when the d.c. service voltage of the system supplied requires to be raised. A larger service voltage, therefore, with the same line drop will give a greater length of line, that is, if the line drop is fixed, any increase in the service voltage makes possible a corresponding increase in the distance between substations. If the load increases directly as the length of the line, then the distance between substations and consequently the length of the transmission line will vary directly as the increase in service voltage, the line drop having the same value in all cases. If, on the other hand, the line is extended and the load remains constant, then the distance between the substations will vary as the square of the voltage increases. In actual practice, however, the true value is the average of the two extremes, that is, if the voltage is doubled the distance between substations is tripled, and with 3 times the voltage the distance will be 5 times as great. It therefore becomes evident that if in traction systems a high d.c. voltage is used the number of substations is reduced and a great saving in the cost of installation is afforded.

In Chapter XIII there are enumerated a number of con-

siderations which apply to the design of switching arrangements. Point 5 states that the choice of units is determined by the size and kind of service required of the machines. Under the heading of "kind of service" we have the following classification:

1. Direct-current feeding for street or interurban railways. This implies an a.c. central station with substations. The service voltage may be either low (500 to 600 volts) or high (1000 to 1200 volts), and the a.c. may be converted either by synchronous converters or motor-generator sets.

2. Alternating-current single-phase traction service with a.c. central station and substations. The high tension is transformed to a service voltage of from 2100 to 2300. Motor-generator sets are sometimes used to change the frequency, phase or voltage of the supplied current to suit the required conditions.

3. Alternating-current series lighting systems for arc and incandescent lamps, with central station and constant-current transformers. The primary voltage of the transformers is 1100 to 2200, and that of the secondaries depends upon the number of lamps connected to them in series.

4. Power distribution at 110 to 220 volts or 500 volts, alternating or direct current. Direct-current power distribution is analogous to case 1. The direct current may also be supplied through mercury rectifiers. Alternating-current distribution is analogous to case 2.

5. Three-wire system, requiring central station and substations. Motor-generator sets or synchronous converters are used for converting the a.c. into d.c. The service voltage is 110-220.

In any of the above cases transformer banks may be used in the central station to step-up for high tensions for long distance transmission. Where direct current is delivered, the substations are equipped sometimes with storage batteries which are kept as reserve or to be used in service during a part of each day. (See Chapter V.) The converter and transformer stations may be located in the central station itself or in separate buildings or they may be portable. The transformers for a.c. service are often put on poles or the sides of buildings near the places of consumption. (See Chapter XXVI.)

The matter of size of units for a given total station rating is decided by the kind of load and the cost of reserves. The following data were obtained from a number of installations in actual service.

SIZE OF UNITS FOR GIVEN SIZE OF STATION.

Required Kw.	Units.	Reserve.
1,000	Two 500	One 500
2,000	Three 800	One 500
3,000	Four 800	One 800
5,000	One 800 Three 1,500	One 1,500
7,000	Two 3,500	One 3,500
10,000	Three 3,500	One 3,500

Still larger stations employ units of 5000, 8000, 10,000 up to 15,000 kw. The following table showing the rating of some of the more well-known large stations will give a general idea of the development of modern plants.

RATING OF WELL-KNOWN STATIONS.

Station	Present Kw.	Ultimate Kw.
Chicago Edison Co. (Fisk St.)	52,000	100,000
" " " Overload Capacity ..	86,000	158,000
N. Y. Edison Co. (Waterside No. 1)	92,500	92,500
" " " (" " 2)	140,000	140,000
Interborough Rapid Transit Co. (59th St.) ..	50,000	120,000
" " " " (74th St.) ..	47,000	87,000
Boston Edison Co.	51,000	....
N. Y. C & H. R. R. (Port Morris)	20,000	30,000
Pennsylvania R. R. (Long Island)	40,000	50,000

In general, the central station building should be of fireproof construction. It is usually built of brick and steel. The foundations are of concrete resting on solid subsoil (or piling with concrete). The machine foundations should be independent of the building foundations. A traveling crane which will safely carry the heaviest machine parts is essential. Ample space should be allowed for the machines for easy and safe inspection and handling of parts while repairing. With vertical steam turbines sufficient space between the outer casing and the gal-

lery or engine-room floor should be left, to allow both expansion at high temperature and removal of the sections of the casing. In designing the building, future extensions should be taken into account with respect to ultimate symmetrical arrangements of the machines and to continued running while building annexes or while installing new machines.

CHAPTER XXV

TYPICAL CENTRAL STATIONS

CONEY ISLAND AND BROOKLYN RAILROAD

THIS system controls three independent d.c. central stations, conveniently located with respect to the three main lines of traffic. The one is in De Kalb Avenue, the second in Smith Street, and the third in King's Highway. The latter is used only during the summer when traffic to the pleasure resorts at Coney Island is heavy. The equipment of all three stations is largely composed of old machines, which are not equal to the increase in traffic, and the company therefore decided to convert the d.c. installation into an alternating-direct current system. A change of this kind in a service like that between New York and Brooklyn can only be accomplished gradually. It was also planned to keep some of the oldest d.c. machines as reserve and to maintain two of the latest types in service. The following arrangement resulted from these considerations. An extension will be built to the largest of the three stations in Smith and 9th Streets, making an 11,000-volt a.c. central station with two 2000-kw. Curtis turbines. The extension is to contain a substation with two 1000-kw. converters, and the d.c. reserve and the 800-kw. d.c. machine which is to be kept in service will be kept in the old part of the power house. The other two d.c. central stations will be replaced by substations. The boiler room and water and coal supply arrangements must evidently be adapted to the larger a.c. central station. The author's designs for the electrical part of the extension which were adopted with slight changes are given herewith.

The plan, cross section and outline of the engine room and gallery are shown in Figs. 235, 236, 237 and 238. From the two turbo-generators, the lead-covered, three-conductor cables are

passed through the foundations in clay tiles to the middle column supporting the gallery. They then lead up this column to the engine-room floor, where they diverge and run half way up the columns on opposite sides.

This arrangement has been somewhat changed, so that now there are three separate cables leading from a terminal box on the turbine to the basement. These then run along the basement ceiling to the columns.

The three phases are separated in an end bell, at which point they diverge, and after passing through the series transformers reach the terminals of the generator oil switches (type H3). Note that these switches are set up in the front part of the gallery. The gallery is not large enough to allow setting all the necessary oil switches in one row, and still keep sufficient space for operating. The series transformers are placed on the gallery ceiling.

The second change that was made was to place the generator oil switches on a compartment at the same height as the other oil switches, and the series transformers were put into these compartments.

The shunt transformers are in a cell back of the generator oil switch cell, and their fuses are mounted on a separate slate base, and may be used as disconnecting switches. There are no disconnecting switches on the generator side of the oil switches, for it is assumed that the oil switch will be accessible when open, i.e., when disconnected from the busbars, and when its corresponding turbine is not running. From the generator switches, the cables run to the disconnecting switches through which they are connected to the busbars. The buses are enclosed in compartments back of the feeder oil switches. The walls are of brick and the covers of slate, and the openings for the cable connections are on the front side. Over the busbars there are mounted the cells containing the shunt transformers for the feeder instruments with the necessary fuses. Their cells are similar to those for the generator shunt transformers. The feeder and converter oil switches are set up in a row with the door side towards the rear wall.

The plan of the gallery shows that the rows of oil switch cells and the corresponding disconnecting switch compartments are broken at about the center. These breaks are neces-

sary to afford room for operating the bus sectionalizing switches, which are inserted for the purpose of dividing the entire equipment into two distinct parts. On each side of the section switches there are connected to the buses one generator,

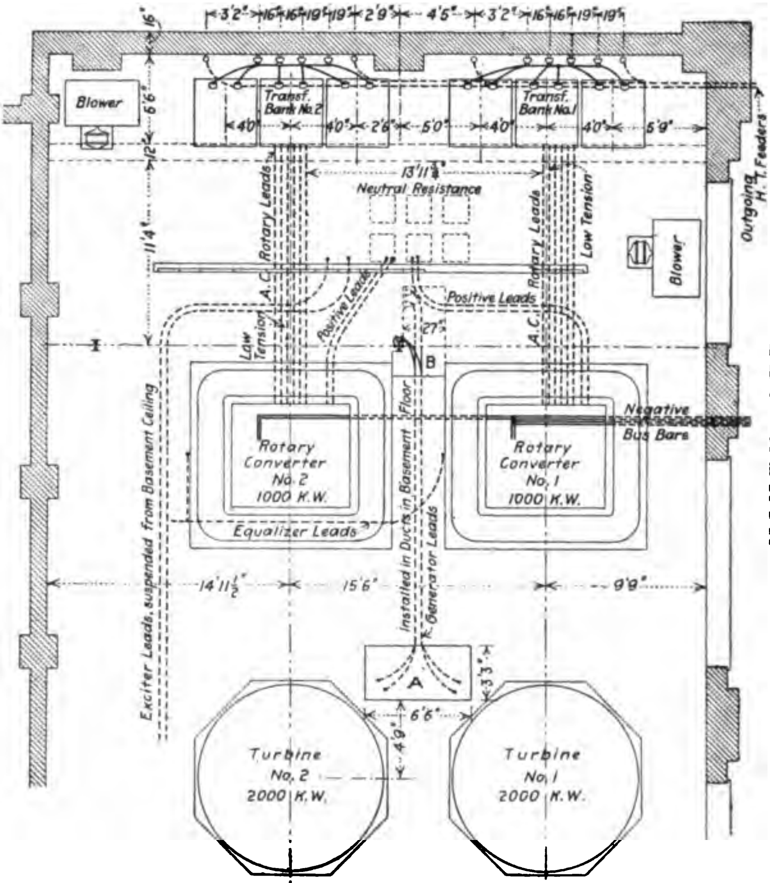


FIG. 235.—Plan View of Engine Floor and Basement of the Coney Island and Brooklyn R. R. Co. Power House Extension.

one synchronous converter and two feeders. The two substations are connected to both sides of the buses each by two sets of feeders, and a reserve switch is provided on the side towards the old building. The feeder oil switches are provided with disconnecting switches on both sides. Those on the bus-

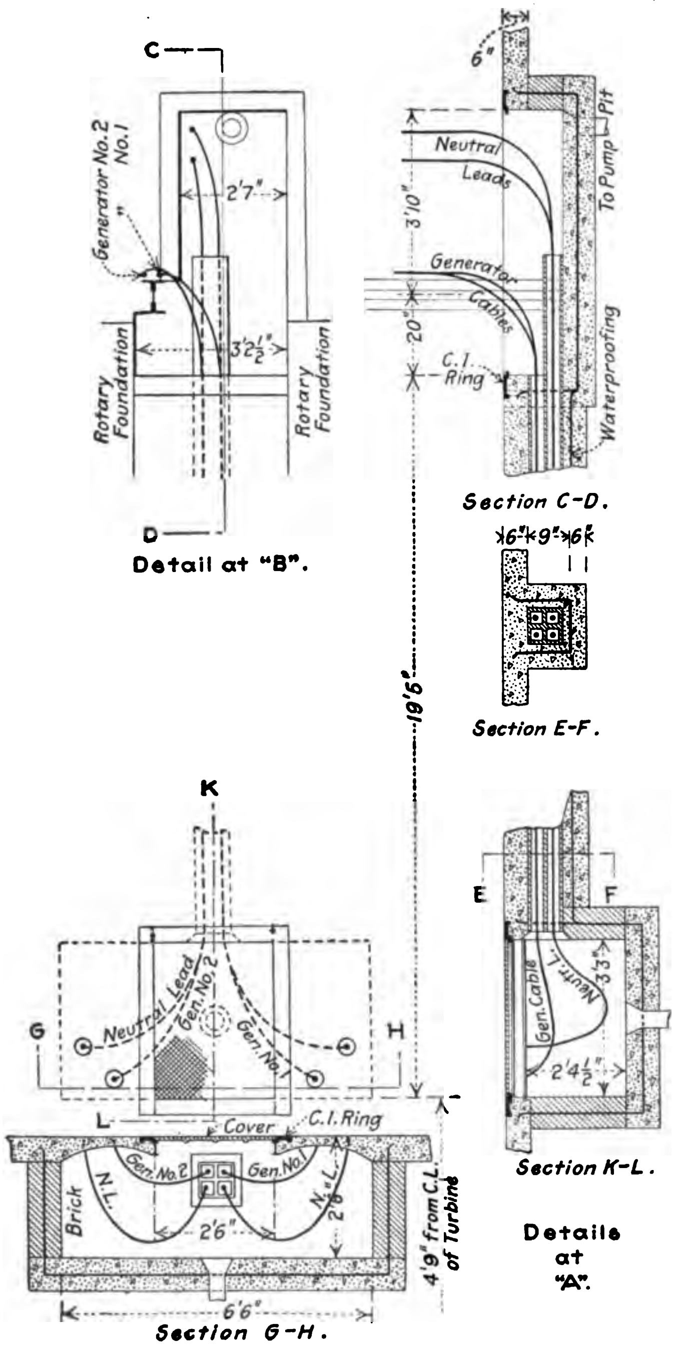


FIG. 236.—Handholes and Ducts for the Generator Cables, Coney Island and Brooklyn R. R. Co.

bar side are mounted in a row of compartments facing the front of the gallery, and those on the feeder side are on the terminals of the oil switches in separate compartments under the oil switch cells. Note that all disconnecting switches are located

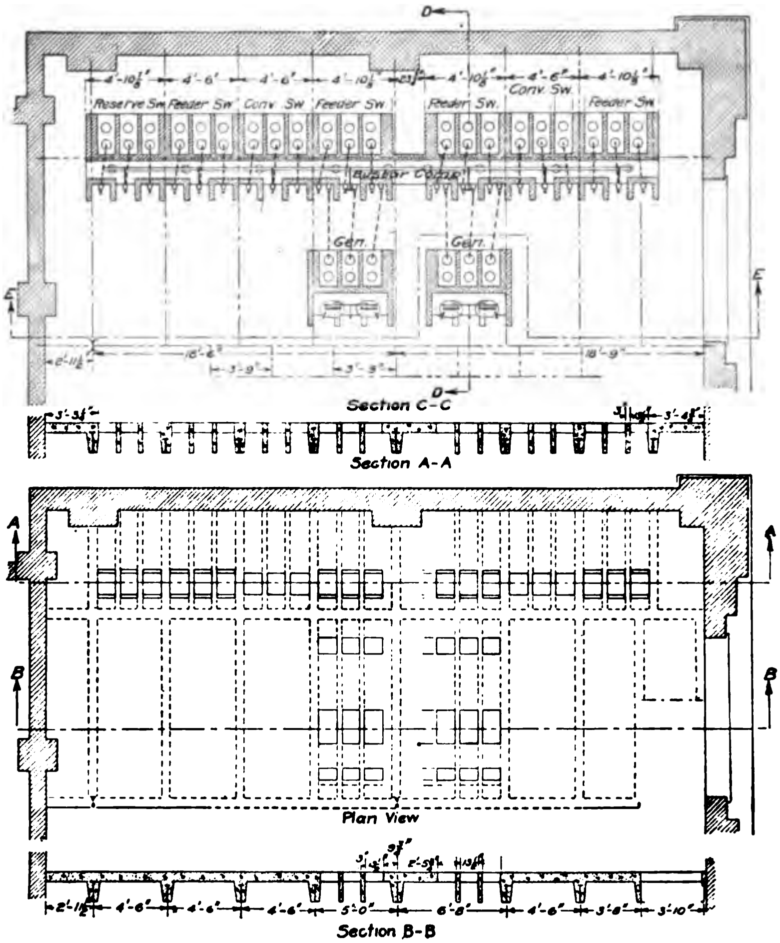


FIG. 237a.—Plan and Construction of Switchboard Gallery, Coney Island and Brooklyn R. R. Co.

on the same gallery together with their oil switches. This has the advantage that the attendant may easily assure himself that the oil switch which he is inspecting or repairing is dead and that it remains so while handling it. The feeders are run

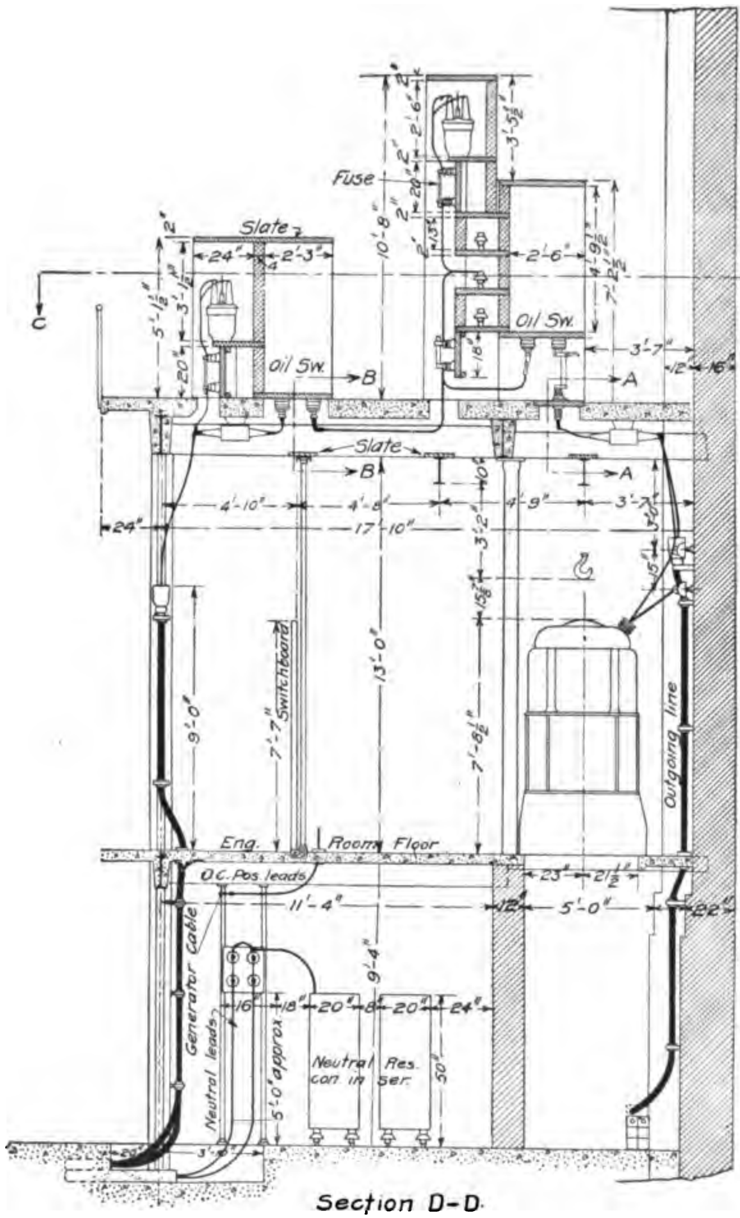


Fig 237b.—Cross Section Through Electric Galleries of Coney Island and Brooklyn R. R. Co. Power House Extension.

out of the station underground in tile ducts as lead-covered. three-conductor cables. The converter oil switches as mentioned above, are located in the same row as those for the feeders, but are furnished with only one set of disconnecting switches and these on the busbar side. They are omitted on the transformer side for the same reason that they are left out on the generator side of generator oil switches, namely, that the oil switch is inspected when it is open and disconnected from the busbars, and when the converter is not running. On the engine-room floor under the gallery there are set up two sets of three single-phase 375-kw. air-cooled transformers. The transformation ratio of these Y-connected transformers is 11,000 to 430 volts. The twelve low-tension cables run along

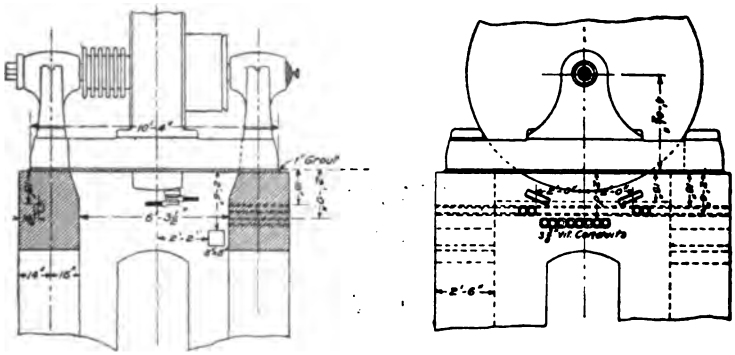


FIG. 239.—Concrete Foundation with Ducts Installed for a Converter.

the basement ceiling in two rows to their starting panels, whence six cables lead through the foundations of the converters to the brushes of the collector rings. Fig. 239 is a detail drawing of the foundations of one of the converters, showing the relative positions of the ducts and openings for the cables and busbars.

A wall shuts off the rear part of the basement and the air circulation for the air-cooled transformers in the resulting chamber is produced by two blower sets placed on the engine-room floor. The blower on the right side towards Ninth Street is joined to the chamber by a sheet metal air passage. The other, which is located directly over the chamber on the left side, will have to be removed in case of any further extension.

The transformers are set up over the chamber on air-tight frame supports of channels and I beams. In order that the transformers may be removed, two traveling differential pulleys running on tracks fastened overhead to the gallery beams are provided. If a transformer is to be moved, therefore, it is first raised by the pulley directly over the transformer row and a small carriage is run underneath, while the opening in the air chamber is closed. The carriage is then run under the second hoist, which carries the transformer between the back of the switchboard and the row of transformers to the left wall, where it can be handled by the main crane.

The plan and elevation of the gallery show the construction of the separating barriers between the different phases and the series transformers on the gallery floor. All of the concrete work is reinforced. The floor is 7 in. thick on account of the conduits for the secondaries of the instrument transformers which are built into it. The switchboard is made up of two generator panels, two feeder panels, controlling two feeders each, one synchronous converter panel equipped with the controlling apparatus and instruments for the two present converters, and having space for the third machine eventually to be installed. Beside this it carries the starting switches for converter No. 2, in front of which it is located. Following these come the two exciter panels and three panels for the d.c. side of the converter. In front of converter No. 1 a starting panel is set up which is in line with the main board. The space between this panel and the main switchboard is reserved for the five 16-in. d.c. feeder panels ultimately to be transferred from the other side of the building. The main board is held on pipe supports running up to a channel on the gallery, and rests on a wooden strip one inch above the floor. The positive cables are led from the converters along the basement ceiling to the d.c. board. The negative buses are laid in the foundations, in openings 8 in. by 8 in. The generator neutrals are led from the turbines to the resistance in the basement floor in the same set of ducts as the generator cables. The resistance for the neutral is grounded. Manholes and ducts are made water-tight and are provided with sewer connections for drainage since they lie below the level of the extreme high-water mark of the adjacent Gaudemus Channel. These plans were laid out be-

fore designing any of the structural work, so that the latter might be fitted to the former.

WATERSIDE STATION NO. 2 OF THE NEW YORK EDISON COMPANY

The New York Edison Company delivers direct-current distribution to motors and lamps mainly to the Borough of Manhattan of New York. A high-tension alternating current is generated in two central stations whose busbars are inter-con-

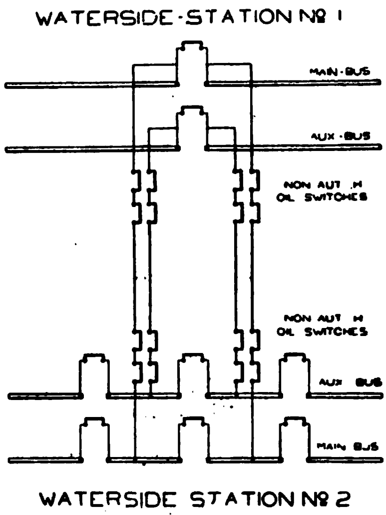


Fig. 240.—Diagram of High Tension Connections between Waterside Stations of New York Edison Company.

nected and the direct current is distributed from twenty-three substations.

Fig. 240 is a diagram of the high-tension connections between the two power houses. The main auxiliary buses are connected together by two sets of cables each. Note that each of the connections contains two non-automatic H3 oil switches in series in each of the stations. The reason for making this connection, as well as others to be described later, specially secure is due to the fact that as the company supplies the most densely populated portion of the city, it is imperative to maintain the service absolutely without interruption under all cir-

cumstances. In the figure there are shown the sub-divisions of the buses of the two stations. The busbars of the new Waterside station have four sub-divisions which give greater flexibility of the generator-feeder group units.

Since it has become possible to concentrate the output of a number of stations, a great reduction in initial cost and operating and maintenance expenses has resulted. On the other hand, however, this has increased the risk of interruption of the service, since if the one station is disabled the whole system is crippled. To reduce this danger as far as possible the different parts of large stations are divided into groups of units which can be worked together or independently as desired. By sub-divisions in the boiler room, by independent installation of the turbo-generators with their accessories, by separate laying of cables and sub-divisions in busbars, a group composed of the above parts can be run as an independent unit.

This is the method adopted in the Waterside station No. 2. At present the station equipment consists of two Westinghouse-Parsons steam turbines on whose shafts are mounted two generators of 7500 kw., 6600 volts, 25 cycles, and 7500 kw., 7500 volts, 60 cycles respectively. Only one of the generators is run at any one time. Besides this there are six Curtis turbines with generators of 8000 kw., 6600 volts, 25 cycles. Two additional Curtis turbines with 14,000-kw., 25-cycle generators are to be installed in the near future. Four exciters of 150 kw., 280 volts each, driven by a 220-hp., 6600-volt, three-phase 25-cycle induction motor, supply the excitation. Two storage batteries are used as a reserve for the exciters. Sixty-four high-tension feeders at 25 cycles and eight at 60 cycles are supplied by the station.

Figs. 241, 242 and 243 show the connections of a generator and feeder and a cross section through the galleries. The cross section is taken at the feeders, so that Figs. 241 and 242 will be described first. It was mentioned above that each busbar set is divided into four parts. (This applies to the 25-cycle buses. The 60-cycle buses have an independent sub-division.)

From corresponding divisions of the buses cables are led to two automatic H3 oil switches. They are connected to the buses by means of disconnecting switches. (Fig. 242.) The buses and disconnecting switches are located in compartments

on the first mezzanine. (Fig. 243.) The selector switches mentioned above are on the second mezzanine and are interlocked to prevent closing both of them at the same time. The main feeders which are connected to either set of buses through the selector switches diverge on the fourth mezzanine into two outgoing feeders connected to separate automatic H3 oil switches and to the two end bells to which the three-conductor cables are joined. On the third mezzanine are the shunt transformers, mounted in compartments with their disconnecting switches. The three-conductor cables are laid in the division and main walls and are led out of the station underground in tile ducts.

Fig. 243, 1st mezzanine. The busbar compartments are separated from each other and from the walls by corridors, the inner one of which is used for operating the disconnecting switches and the other one for inspecting the busbars and insulators, which are accessible through small doors in the back of the compartment. The disconnecting switches are double-break switches, first disconnecting the cables and then the busbars. Tie oil switches are inserted between the divisions of the busbar sets. (See Fig. 240.) These are set up in line with the busbars in separate divisions, so that the whole mezzanine is divided into a series of chambers containing alternately sections of the busbars and the bus-tie oil switches. The chambers are connected with doors. The tie oil switches are connected to the buses through disconnecting switches as indicated by the bottom switch in the first mezzanine.

On the second mezzanine the selector switches are mounted back to back. The outer corridor is for inspection of the oil switches, and the main feeders are led up in the space between them. The series transformers are also placed on this mezzanine, being built into the feeders as shown.

On the third mezzanine there are set up the shunt transformers with their disconnecting switches. The two outer corridors are moved over towards the middle of the gallery to make room for the end bells and three-conductor cables and the series transformers. The secondaries of the shunt transformers are laid in tiles imbedded in the concrete floor.

The fourth floor is similar to the first, with the addition of a false floor for the outgoing feeders. All control and instru-

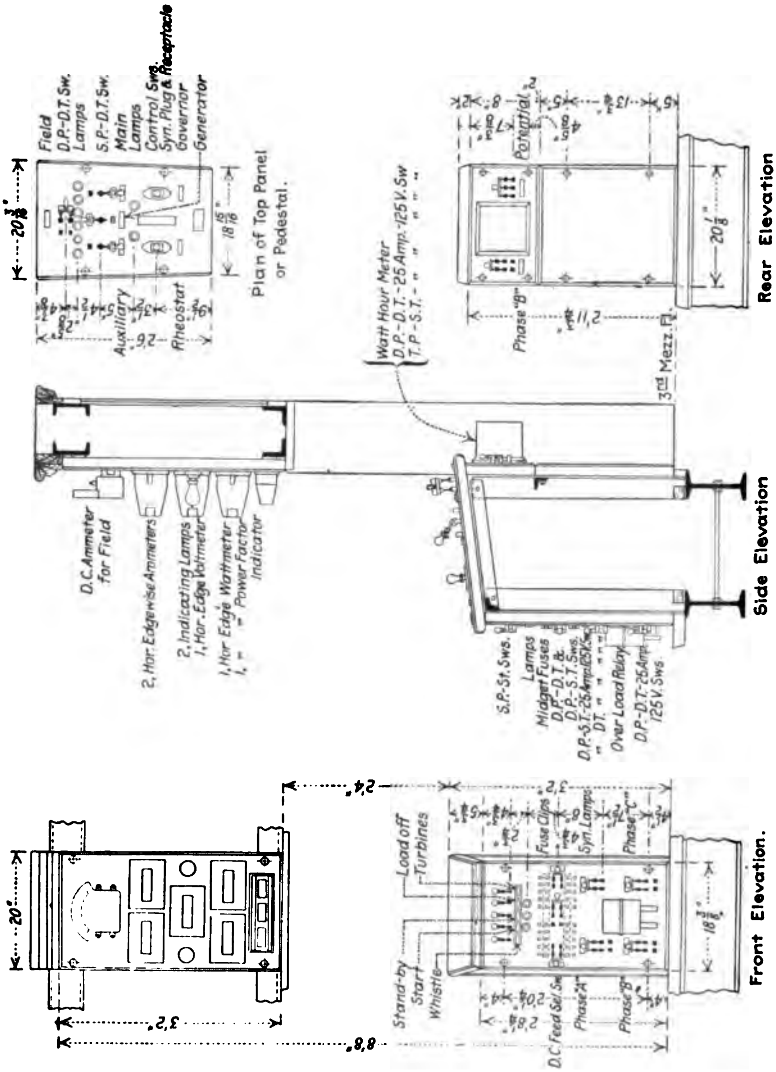


FIG. 245.—Generator Control 25-Cycle Pedestal and Instrument Panel. (New York Edison Company, Waterside Station No. 2.)

ment wires are led up through the wall to a frame support on the sixth mezzanine, whence they run to the switchboards.

Figs. 241 and 243. The generator cables are led in through the floor in conduits up to the division wall, whence they pass up the wall to the electrically operated non-automatic oil switches in the fourth floor. From here they are led back to the second floor in the same way as the main feeders, to the non-automatic type H3 selector switches which join them to their respective buses. These switches are interlocked so that only one can be closed at a time. The connections between selector switches and busbars are made through double-break disconnecting switches. The generator shunt transformers are set up in line with those for the feeders, and the series transformers are mounted on the division wall. On the fourth mezzanine there are also located the station-tie oil switches, which tie feeders are led along the division wall to the ducts in the basement floor. The exciters, the field rheostats with their motors, the d.c. switchboard and the exciter buses are located on the main floor of the high-tension division. The annex is really nothing more than a part of the main power house shut off by a division parallel to the north side of the building. It is completely separated from the engine room and is a complete fireproof building in itself. The main operating room with the main switchboards is situated on the third mezzanine on the west side of the building, on a balcony facing the engine room. The generator and feeder panels are grouped in two independent switchboards. (See Fig. 244.) On the engine room side facing the inner part of the balcony are set up the control benches and instrument boards for the generator, and station-tie and bus-tie oil switches. The bench board is arc-shaped. (Figs. 245, 246 and 247.) Opposite to this board there is set up a double semicircular row of panels for the feeder control. (Fig. 248.) This makes a very compact arrangement and the entire large system is very economically and safely controlled from a comparatively small space and with a small number of attendants. The instrument boards over the benches are set up so as not to obstruct the view over the station. Ample light is obtained through the engine-room skylight and the windows on the west side.

Figs. 241 and 245 show the connections and location of all

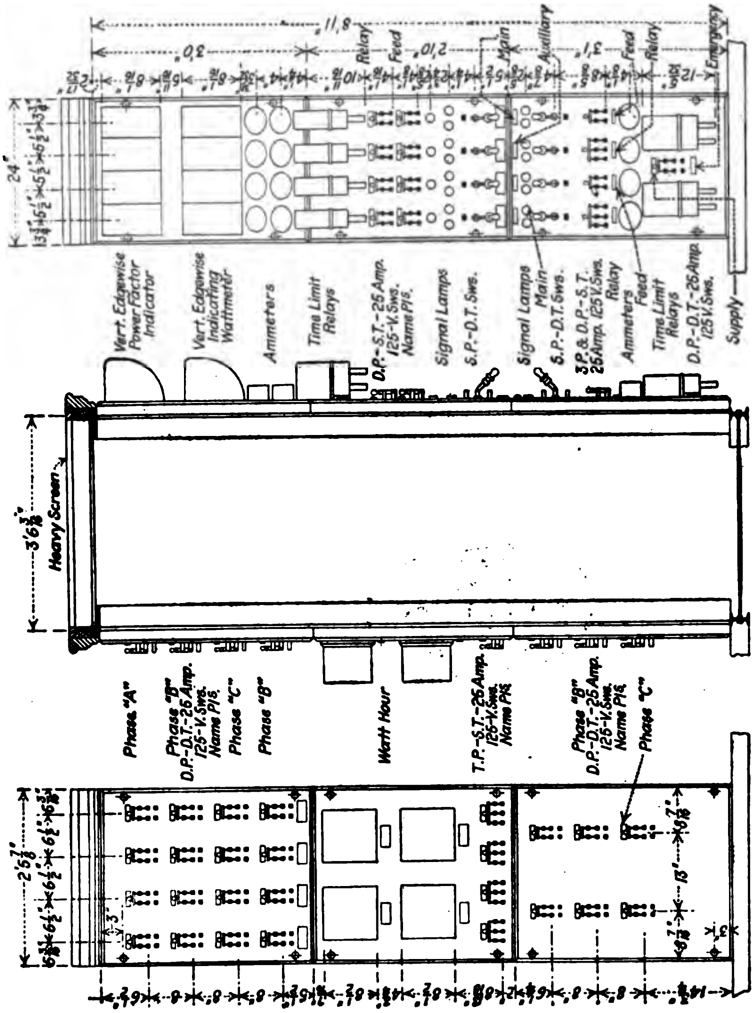


FIG. 247.—High Tension Feeder Control Panels for 25 Cycles. (New York Edison Company, Waterside Station No. 2.)

the control apparatus and instruments for a 25-cycle generator. Every generator has its own bench and instrument board made of blue Vermont marble, the general dimensions of which are given on the drawings.

All the equipments specified below are taken from the specification book by permission of the New York Edison Company.

The equipment for each generator is as follows:

1-500 Weston ammeter and shunt.

2 Horizontal edgewise ammeters, 2000-amp. scale.

1 Horizontal edgewise voltmeter, 8000-volt scale and 150-volt winding.

1 Horizontal edgewise three-phase wattmeter, 22,000 kw. scale.

1 Horizontal edgewise power-factor indicator, 110 volts, 60-100-60 per cent.

1 Balanced three-phase induction watt-hour meter, rectangular pattern.

2 Lamp sockets for mounting on front of panel. One for overload lamp and one for synchronizing lamp.

3 S. P. D. T. control switches, one for main generator "H" oil switch, and two for generator selector "H" switches.

6 Bull's eye indicating lamps and sockets three green and three red bull's eyes.

1 Four-point synchronizing receptacle.

2 Engine-governor controlling switches, one for the turbine governor, and one for the electrically operated field rheostat dial.

5 Bull's eye indicating lamp receptacles and 5 plain bull's eyes.

3 D. P. S. T. 25-amp., 125-volt lever switches, one for synchronizing lamps, one for d.c. feed to generator "H" and one for d.c. feed to selector "H's."

5 D. P. D. T. 25-amp., 125-volt lever switches, four for short-circuiting secondaries of four generator series transformers, and one for d.c. supply.

1 D. P. overload instantaneous relay for lighting an overload lamp.

The relay has one standard coil and the other wound for 1.73 times the standard.

1 T. P. S. T. 25-amp., 125-volt lever switch for opening potential leads to the watt-hour meter.

4 2000-amp. series transformers, ratio 400: 1.

3 T. P. S. T. 1200-amp., 6600-volt, form H3 oil switches with 8 in. pots and 220-volt motors.

2 6600 to 110-volt, 200-watt shunt transformers.

2 S. P. S. T. 500-amp., electrically operated field switches with discharge clips and resistance.

1 D. P. D. T. control switch for controlling electrically operated field switches.

5 S. P. S. T. signal switches.

20 Pairs of fuse clips.

18 Name plates.

5 6600-volt disconnecting switches and fuses for shunt transformers.

6 S. P. S. T. disconnecting switches for 1200 amp., 6600 volts.

Station instruments for the synchroscope are placed on a swinging panel in the center of the bench board (see Fig. 217), whose equipment is as follows:

2 Synchronism indicators, 13 in. diameter.

1 350-volt horizontal edgewise voltmeter.

1 D. P. D. T. 25-amp., 250-volt lever switch.

Figs. 246 and 247 also show the equipment for the station tie control. Only that part located in Waterside Station No. 2 is shown. It consists of the following:

8. T. P. S. T. 1200-amp., 6600-volt, form H3 oil switches with 8-in pots, 220-volt motors.

8 S. P. D. T. controlling switches.

16 Indicating lamps and sockets.

8 Pairs of red and green bull's eyes.

12 Series transformers, 1500 amp., ratio 300: 1.

4 D. P. overload time-limit relays, diaphragm type, with one special coil to take 1.73 times the normal current.

8 Horizontal edgewise ammeters, 10-1500 amp.

4 Wattmeters, balanced 3-phase scale 18,000-0-18,000 kw.

12 660-volt disconnecting switches and fuses for shunt transformers.

8 6600 110-volt, 200-watt shunt transformers.

4 Four-point synchronizing receptacles.

2 Four-point synchronizing plugs.

16 D. P. D. T. 25-amp., 250-volt lever switches.

8 Lamp sockets.

16 D. P. S. T. 25-amp., 250-volt lever switches.

12 1200-amp., 6600-volt disconnecting switches, with locking devices.

4 Horizontal edgewise voltmeters, 5000 to 7500 volts.

3 6600-volt disconnecting switches and separate fuses for bus shunt transformers.

8 Lamp sockets for overload and synchronizing lamps.

84 Name plates.

Figs. 242 and 248 show the control apparatus and instruments for a feeder board consisting of two panels placed back to back. Each board controls four outgoing feeders, the equipment tabulated below is for one feeder.

1 Vertical edgewise 60-100-60 per cent. power-factor indicators, 110 volts, 5 amp.

1 Vertical edgewise balanced three-phase wattmeters, scale 0-3500 kw.

1 Pocket type a.c. ammeter, 300-amp. scale, 5-amp. winding.

1 Pocket type ammeter, 300-amp. scale, 10-amp. winding.

4 Series transformers, 300 amp., ratio 60: 1.

2 200-watt shunt transformers, 6600 to 110 volts.

4 Fuses for above transformers with 6600-volt disconnecting switches.

1 D. P. time-limit overload relays, diaphragm type, mounted edgewise to board. One special coil to take 1.73 times normal current.

2 D. P. S. T. 25-amp., 250-volt lever switches.

4 D. P. D. T. 25-amp., 250-volt lever switches.

1 Balanced 3-phase induction watt-hour meter, rectangular pattern, for mounting on the rear panels.

3 Indicating lamps and sockets.

1 White, 1 green and 1 red bull's eye.

1 T. P. S. T. 25-amp., 250-volt lever switch.

1 S. P. D. T. controlling switch.

1 T. P. S. T. 300-amp., 6600-volt, 8-in. pot form H3 oil switch and 220-volt motor.

Equipment for selector section:

8 Indicating lamps and sockets.

4 Pairs red and green bull's eyes.

2 T. P. S. T. 25-amp., 250-volt lever switches.

4 S. P. D. T. controlling switches.

2 D. P. S. T. 25-amp., 250-volt lever switches.

7 D. P. D. T. 25-amp., 250-volt lever switches.

2 Pocket type ammeters, 600-amp. scale, and 5-amp. winding.

2 Pocket type ammeters, 600-amp. scale, and 10-amp. winding.

6 Series transformers, 600-amp. rating, ratio 120: 1.

2 D. P. overload time-limit relays, diaphragm type, mounted flat on panel. One special coil to take 1.73 times normal current.

4 T. P. S. T. 500-amp., 6000-volt form H3 oil switches with 8-in. pot and 220-volt motors.

12 6600-volt, 800-amp. S. P. S. T. disconnecting switches with locking devices.

The equipment for 2000-amp. bus-section tie consists of:

6 T. P. S. T., 2000-amp., 6600-volt, form H-3 oil switches with 8-in. pots and 220-volt motors.

6 S. P. D. T. controlling switches.

24 Indicating lamps and sockets.

12 Plain bull's eyes.

6 Pairs red and green bull's eyes.

8 6600 110-volt, 200-watt shunt transformers.

3 D. P. D. T. 25-amp., 250-volt lever switches.

36 6600-volt, 2000-amp. S. P. S. T. disconnecting switches with locking devices.

8 Horizontal edgewise frequency indicators for 25 cycles.

16 Fuses and 6600-volt disconnecting switches for shunt transformers.

8 Horizontal edgewise voltmeters, scale 5000-7500.

6 D. P. S. T. 25-amp., 250-volt lever switches.

10 Name plates.

The generator and feeder for 60 cycles are similar to those described above for 25 cycles with corresponding changes in the ratings of the instruments.

Besides carrying the equipment for the generator and bus and station ties, the bench boards are provided with signal apparatus for use as a means of transmitting signals between operators on the high and low-tension switchboards and the engineer stationed at the turbine throttle. Provision is made

for three sets of signals. One is for regulating the turbine governor and is transmitted through illuminated signs located on the west wall of the engine room, and is used in conjunction with the signal whistle located on the south division wall. The other signals relate to the starting or stopping of the turbines and are transmitted to the engineer direct through the signal stand located near the turbine throttle. The third signal is a call whistle from the d.c. control board on the first floor electrical gallery. The signal equipment for regulating the governor consists of the following apparatus:

20 S. P. S. T. signal switches located on the front of the generator pedestals (two for each pedestal), for operating whistle relay and flashing turbine number.

10 S. P. D. T. knife switches located on top of pedestal, under synchroscope panel.

With these switches there may be flashed individually the turbine number and the red or green engine signal of the illuminating sign.

1 D. P. D. T. 25-amp. knife switch together with special copper strap connection and 24 sets of ferule type enclosed arc fuses and clips, forming the d.c. fuse panel on front of the pedestal under the synchroscope.

1 Relay oil switch with lever for hand operation, located on top of the center pedestal of the generator control board under the synchroscope panel.

The magnet for this relay is wound with 1800 turns of No. 26 double cotton covered magnet wire.

1 "di-el-ite" resistance unit of 465 ohms 116 watts for external resistance in the relay coil circuit.

1 Magnet on 250-volt circuit, of sufficient pull to operate a 3.5-in. steam signal whistle. This magnet is located near the whistle on the south division wall in the engine room.

1 Illuminated sign for the turbine numbers and the engine signals located on the west wall of the engine room.

This sign consists of a substantial sheet iron box with angle iron framework set flush with the engine-room wall and displaying the stenciled turbine numbers from 1 to 10 inclusive. Above each numeral is a separate ground glass signal panel to indicate red for "raise" and below a similar signal panel indicating green for "lower," as the case may be. Within the

sheet iron box are the lamps and circuits for illuminating the turbine numbers and the colored signals mentioned. For connecting up this device there are required the following cables:

2 12-conductor No. 14 wire lead covered cables approximately 30 ft. long. There are $\frac{2}{32}$ in. rubber over each wire, two tapes and $\frac{5}{64}$ in. lead over all.

1 19-conductor No. 14 wire lead covered cable, approximately 30 ft. long. There are $\frac{2}{32}$ in. rubber over each wire, two tapes and $\frac{5}{64}$ in. lead over all.

1 Twin wire cable, lead covered, consisting of two No. 10 wires, each wire having $\frac{5}{16}$ in. rubber and $\frac{1}{16}$ in. lead over both.

With the above specified apparatus, the operator at any one of the generator pedestals is able to blow the signal whistle and flash the turbine number. He is also able to blow the signal whistle from the center pedestal and flash either the red or green signal, together with any of its corresponding turbine numbers.

The wiring diagram and apparatus used for signaling the engineers to start up or shut down the turbines is shown in Figs. 241 and 245. The complete list of apparatus required is as follows:

30 S. P. S. T. signal switches, located on the front of the generator pedestals, three for each pedestal, together with three plain signal lamps and receptacles. The name plates are labeled respectively, " Start," " Stand by," " Load off."

10 Special signal devices mounted on front of generator instrument panels, one for each panel, and each consisting of a malleable iron box of dark marine finish. On a ground glass face are painted in 0.5 in. black letters the three signals: " Full Speed," " O.K.," " Shut Down."

Each of these outfits contains six miniature frosted lamps and screw bases.

8 Turbine signal devices on stands complete, each consisting of 1.25-in. iron pipe stand and special cast iron front with oxidized bronze finish on which are mounted the following:

1 Horizontal edgewise frequency indicator.

1 Engine signal device consisting of malleable iron box, oxidized bronze finish. On a ground glass face are painted in 0.5 in. black letters the signals: " Stand by," " Start," " Load

Off," "Full Speed," "O.K.," "Shut Down," illuminated by 12 miniature frosted lamps on screw bases.

1 Gang of three signal knife switches enclosed in a cast iron box, oxidized bronze finish.

2 Turbine signal devices, similar to the above except that they are mounted on the west wall of engine room and each have in addition to the above, a frequency indicator for the 60-cycle generator.

For connecting up this apparatus the following cables are required:

10 19-conductor No. 14 wire control cables, one for each turbine signal.

This apparatus enables the operator at the high-tension generator control pedestal to flash the following signals to the engineer standing at the turbine throttle, "Start," "Stand by," "Load off," and to receive in turn signals from the engineer as follows: "Full Speed," "O.K.," "Shut Down."

The following cables are required for the generator control for each unit.

2 7-conductor No. 14 wire cables, for the control of the H oil switches on the second and fourth mezzanine floor.

1 19-conductor cable of eight No. 10 wires and eleven No. 14 wires for connecting the shunt and series transformers with the controlling board.

1 19-conductor cable, No. 14 wire, between the generator and control board for the engine signal and governor control device.

1 12-conductor cable No. 14 wire for controlling the electrically operated field rheostats located on the first floor of the electrical gallery.

The generator cables comprise per unit:

3 1,500,000-cir. mil. cables, cotton covered from the terminal board on the generator to the end bell at the base of the generator foundation, lead covered from the end bell in the wall of the third mezzanine of electrical gallery; cotton covered from this point to the bus disconnecting switches.

2 400,000-cir. mil. cables for the field circuit.

1 No. 6 duplex cable for the field ammeter circuit.

The control cables for each feeder group consist of:

4 7-conductor No. 14 wire cables for the control of the H oil switches.

2 19-conductor (11 No. 14 and 8 No. 10 wires) cables for connecting the series and shunt transformers with the high-tension feeder control boards.

In addition for the high-tension control of motor-generators and exciters, there are furnished:

1 7-conductor No. 14 wire control cable for inter-connecting instruments and signal lamps on exciter board with the high-tension feeder control panel.

The feeder cables comprise:

3 500,000-cir. mil. cables extending from the bus disconnecting switches to the 300-amp. H oil switches on the fourth mezzanine.

6 250,000-cir. mil. cables extending from the H oil switches on the fourth mezzanine to the high-tension triplex feeder end bell on the third mezzanine.

The control cables for the station tie control comprise:

2 7-conductor No. 14 wire cables for controlling the H oil switches.

1 7-conductor No. 14 wire cable for connecting the bus shunt transformers and the bus instrument panel.

1 19-conductor No. 14 wire cable for connecting the shunt and series transformers with the station tie control panel.

The station tie cables comprise:

3 1,000,000-cir. mil. cables extending from the buses up to the point where they end at the high-tension end bell, on the third mezzanine floor.

There are furnished for each pair of bus tie oil switches:

1 12-conductor No. 14 wire control cable for controlling each pair of 2000-amp. bus-tie oil switches.

The specifications for all of the above mentioned cables are as follows:

1,500,000-cir. mil. cable, $\frac{10}{32}$ in. varnished cambric insulation, $\frac{1}{8}$ in. lead with 2 per cent. tin.

1,500,000-cir. mil. cable, 37 to 19 wires $\frac{10}{32}$ in. varnished cambric insulation, one cotton braid, waxed.

1,000,000-cir. mil. cable $\frac{10}{32}$ in. varnished cambric, one cotton braid, waxed.

500,000-cir. mil. cable of 127 wires $\frac{10}{32}$ in. varnished cambric, one cotton braid waxed.

400,000-cir. mil. cable, $\frac{4}{32}$ in. varnished cambric, lead covered field cables.

250,000-cir. mil. cable, $\frac{10}{32}$ in. varnished cambric, one cotton braid waxed.

No. 00 rheostat wire, 415-No. 25 B. and S. gage wires, $\frac{3}{32}$ in. varnished cambric, one cotton braid painted, and one asbestos braid painted.

No. 6 duplex cable for field ammeter circuit, $\frac{5}{64}$ in. rubber, $\frac{1}{16}$ in. lead.

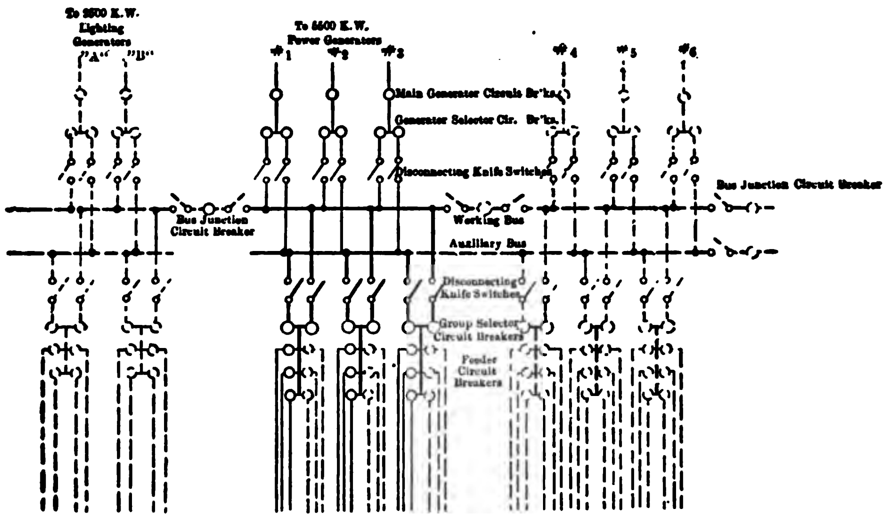


FIG. 248.—Diagram of High-Tension Wiring, Long Island City Power Station. (Westinghouse, Church, Kerr & Co.)

LONG ISLAND CITY POWER STATION.

The western lines of the Long Island R. R. (N. Y.) were the first of this system which were electrified. The tunnel under the East River connecting the Long Island lines with the new depot of the Pennsylvania Railroad being at that time in course of erection. The power station and its chain of substations therefore were at first erected and installed to suit the demands of the electrified western road, nevertheless means were provided for increasing the power capacity.

The present power station contains a machine capacity of about one-fifth of the ultimate installation. There are in-

stalled three steam-turbines of the Westinghouse-Parson type, driving 5500-kw. 11,000-volt alternating current generators. The armature windings are star connected and the neutrals of all the machines are grounded through a common resistance.

Fig. 248 shows the wiring diagram of the high-tension cables, indicated in simple lines. The full lines represent the present installation, and the doted ones the future lay-out. The high-tension cables are run through ducts in the foundation up to the division wall between the engine room and the switching galleries. (See Fig. 250.) They are then run up this wall

FIG. 249.—Feeder Gallery Showing Oil Switches for Feeders and Generators. (Westinghouse, Church, Kerr & Co.)

to a main oil switch set up on the basement or feeder gallery. The backs of the oil switch cells are extended up to the ceiling and are provided with barriers between the phases. Fig. 249 shows the three main oil switches with their extensions in the background on the right hand side. The shunt transformers for the generators are set up in special compartments near the division wall on the same floor. From the main oil switches the cables run along the basement ceiling to the selector switches installed on the first or bus gallery.

Fig. 253 shows a plan of the engine room and bus gallery, showing two rows of cells. Each row at present consists of three groups of two oil switch cells each. The smaller are the

selector switches for the generator. Two opposite oil switches belong to the same machine.

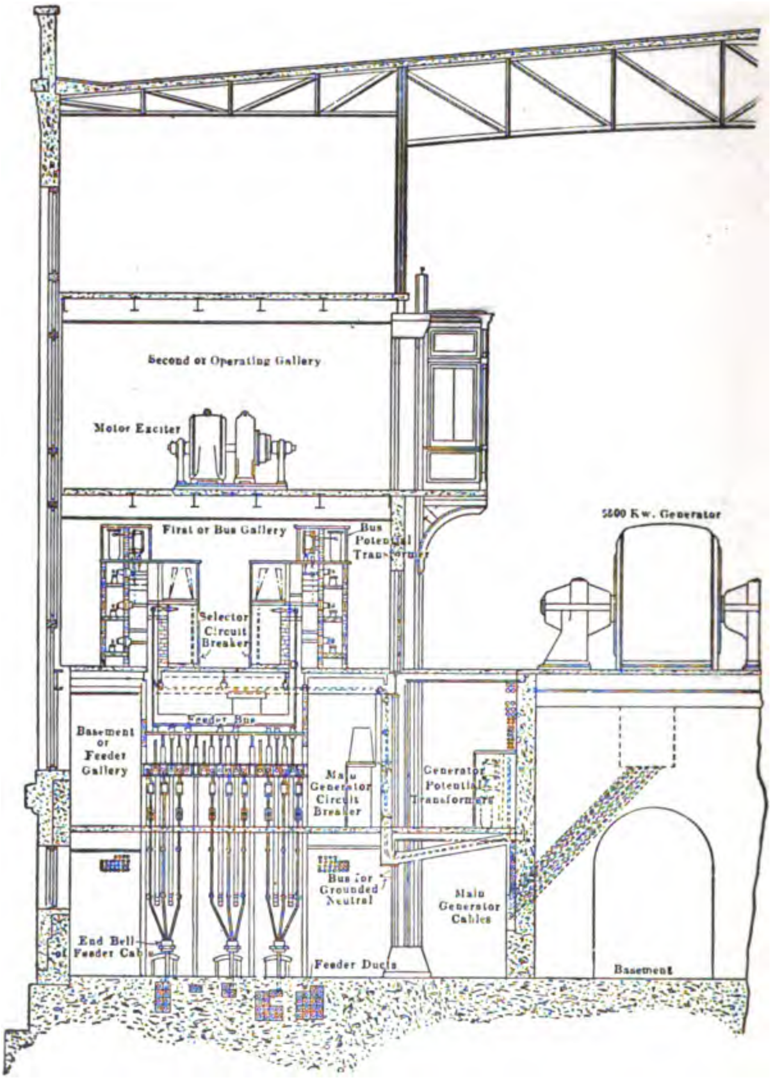


FIG. 250.—Cross Section of Electric Galleries, Long Island City Power Station. (Westinghouse, Church, Kerr & Co., N. Y.)

A compartment containing two sets of disconnecting switches is inserted in each group of oil switches. The cables lead from

the selector switches in compartments on the back of the cells to one set of the disconnecting switches. (See Fig. 251, longitudinal section between buses, and Fig. 252.) They then run across the space between the oil switch structure and the busbar compartment to the corresponding busbars.

The generators are designed to run in parallel on either of two sets of main busbars, called the working and auxiliary buses, only one set of which is generally in use. The three busbars of the working bus are disposed in the three-story bus

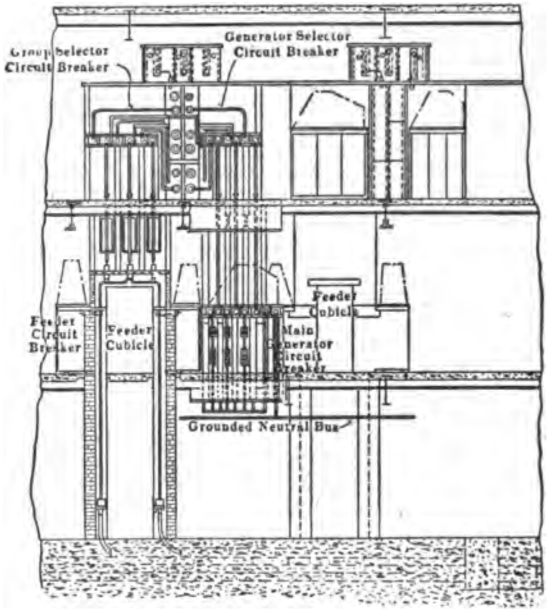


FIG. 251.—Longitudinal Section between Buses. (Westinghouse, Church, Kerr & Co.)

structure of brick and alberene stone along the north side of the gallery, the auxiliary bus being disposed in a similar structure along the south side directly opposite the main bus, and towards the division wall.

As shown in Fig. 248, there are installed at present three main oil switches in the basement and six selector switches on the bus gallery.

Three groups of six feeders each are supplied from the busbars, each of the groups being connected to the two sets of

buses through two group switches. At present only three feeders of each group are in use. The larger oil switches shown in Fig. 252 are the group switches, of which there are two for each feeder group. As noted above each disconnecting switch compartment contains two sets of switches. One connects the generator selector switches to the busbars, and the other joins the buses to the feeder group switches. The cables are led to the back of the group switches in similar compartments or barrier chambers. (See Fig. 251.) Corresponding

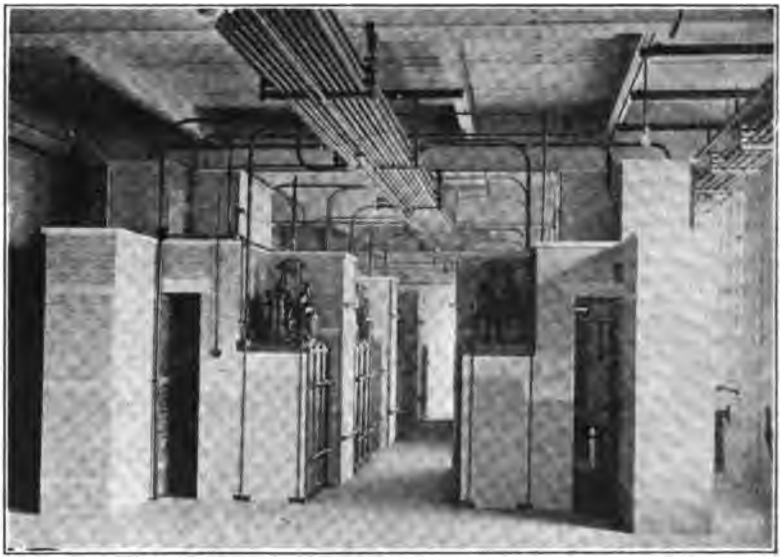


FIG. 252.—Bus Structure and Selector Switches. (Westinghouse, Church, Kerr & Co.)

pairs of group switches are connected under the floor by busbar sets. The latter are contained in brick compartments divided into elongated chambers by a number of cross barriers. These compartments are supported on the basement ceiling, and run across the switching room. The six feeder switches for each feeder group are set up in two rows on either side of the auxiliary busbar compartments, three on each side, and running across the room parallel to the buses. From the small busbar sets cables are run down to the feeder switches.

They then lead down the backs of these and down the wall which extends to the foundations, until they finally reach the end bells of the three-conductor cables. The feeders are led out of the building underground in tile ducts. Fig. 254 shows the connections of the three-conductor cables to the phases. The

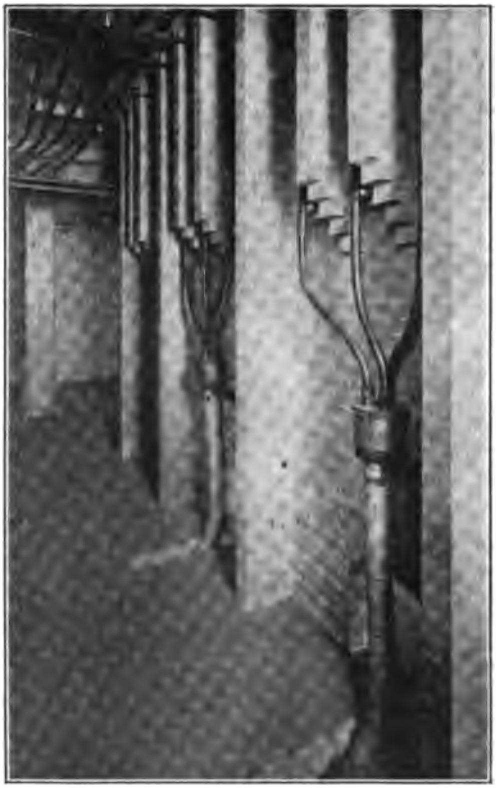


FIG. 254.—High-Tension Feeder Cables in Basement entering Conduits. (Westinghouse, Church, Kerr & Co.)

brick barriers between the phases extend to a level with the tops of the cells, above which they are replaced by asbestos barriers. As each group of feeder switches is set up directly below the corresponding set of group switches, and since the generator main switches are on the same vertical plane with their selector switches, the generator main switches are placed

on the front side of the corridor between the groups of feeder switches. All oil switches thus become easily accessible. The switches employed are all type C Westinghouse electrically operated three-pole switches with the exception of the main generator switch which is four-pole. The fourth pole is for the neutral connection of the machine. All oil switches are built for 600 amp. except the feeder group switches which are for 1200 amp. The pole pairs are enclosed in separate brick chambers with doors on the front side, and closed in on the back by a wall, into which are built the bushings for the incoming and outgoing cables. All cables and connections, including those of the same phase, are separated from each other by brick, soapstone or asbestos barriers. Over the busbar compartments on the engine-room floor there are set up the cells for the necssary shunt transformers and fuses. The busbars are composed of 3 in. by 0.25 in. copper bars supported in separate compartments on heavy insulators. There are a number of openings in the backs of the compartments so that the bus insulators and connections may be inspected. The compartments for the small auxiliary buses in the basement are similarly built with the openings towards the outer wall. The main connections between buses and oil switches are made of strong copper bars mounted on porcelain insulators and enclosed in brick or asbestos compartments.

The four main cables of each machine are 600,000 cir. mils. cross-section with $\frac{10}{32}$ in. varnished cambric insulation, and those between the group switches and small buses are 1,318,000 cir. mils. sectional area. The feeder switches are connected with the three-conductor cables with 250,000-cir. mil. cables, and those between the feeder switches and the transformers which supply the induction motor of the motor exciter set are 73,000 cir. mils. The neutral busbar which connects the neutrals of all the machines to the resistance is a 600,000-cir. mil. cable. All of these cables are covered with $\frac{10}{32}$ in. varnished cambric insulation with double protective braiding. None of the station cables of either high or low-tension are lead covered. The three-conductor cables leading to the high-tension transmission line consist of three 250,000-cir. mil. conductors with $\frac{7}{32}$ in. paper insulation. A further $\frac{7}{32}$ in. insulation encloses all three cables and the whole is covered

with jute and $\frac{9}{64}$ in. of lead. These cables leave the building in ducts laid in the foundations. All of the high-tension three-conductor cables are connected to brass end bells 7.75 in. in diameter and about 5 in. deep, soldered to the lead covering and filled with an insulating compound.

Excitation for the generators is obtained from three different sources. These are: A set of two exciters each driven by its own steam turbine, a motor-generator set and a storage battery. The two Westinghouse-Parsons turbines for the exciters are direct connected to two 200-kw. d.c. generators which deliver 910 amp. at 220 volts. The motor-generator set consists of an induction motor of 290 hp. driven by three-phase alternating current from the low-tension side of the transformer bank at 440 volts. This bank is composed of three 175-kw. oil-cooled transformers, delta connected on the high and low-tension sides. Their high-tension side is connected to the high-tension buses by a feeder of the feeder group. The exciter transformers are set up on the east side of the switching house basement.

The generator of the motor-generator set is of the same rating as the turbine driven machines, and is mounted on the shaft of the induction motor. The turbo-exciters are set up in the engine room, and the motor-generator set on the operating gallery. The storage battery is a very reliable reserve for the machine excitation and for the oil switch solenoids. It consists of 110 cells each containing 7 type R″ chloride accumulator plates as delivered by the Electric Storage Battery Company. There is sufficient space in each cell for 11 plates. The discharge rate of the battery is 366 amp. per hour at a normal pressure of from 180 to 220 volts. It is charged by a 15-hp. induction motor driving a 12.5-kw. booster. This machinery is also set up in the operating gallery, and the battery is placed in a separate chamber in the engine-room basement.

Fig. 255 shows the wiring of the exciter and battery. There are two sets of busbars on the d.c. side, installed under the operating room together with the equalizer buses. The battery or either one of the exciters can be connected through double-throw switches to the main or auxiliary buses. The generator field windings are connected to the main buses by double-pole switches, and the busbar sets can be connected to-

gether with lever switches, so that a generator field may also be excited indirectly from the auxiliary buses.

The entire switching system is controlled from the operating stand at the east end of the second gallery. The present position of the operating room corresponds to what will be the middle of the station when the contemplated addition on the east side is built. (See Fig. 253.)

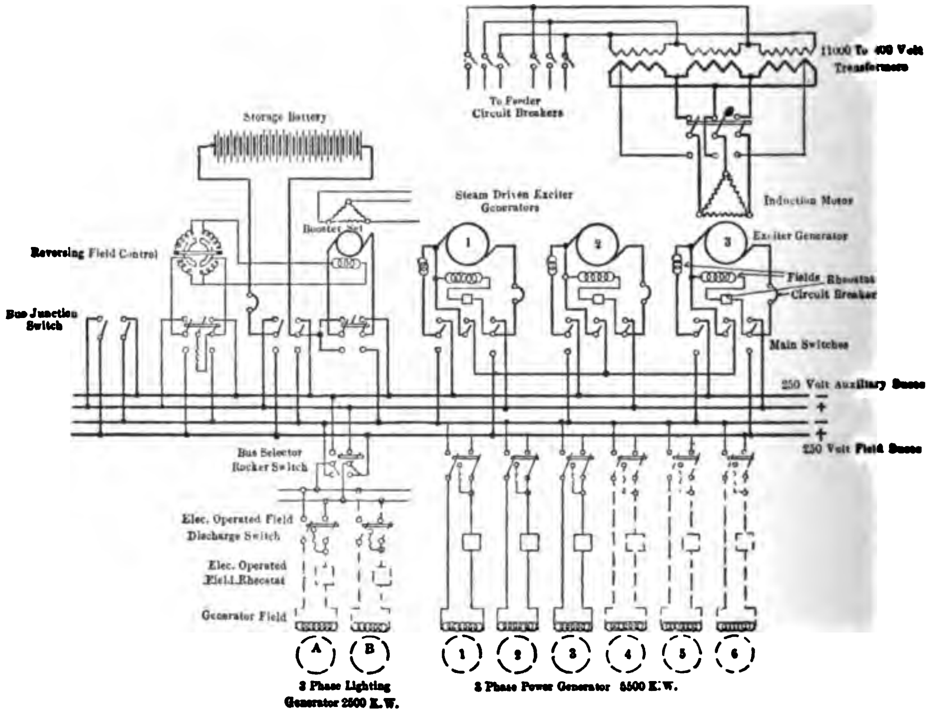


FIG. 255.—Diagram of Low-Tension Wiring. (Westinghouse, Church, Kerr & Co.)

The gallery is about 13 feet over the main engine room and has a small overhanging observation balcony which gives a comprehensive view over the entire station.

The switchboard arrangement consists of (a) generator control bench; (b) greater instrument board directly in front of the bench; (c) feeder control board; (d) exciter switchboard; (e) auxiliary switchboard for station lighting and other purposes. All of the panels are of marble and the panels and in-

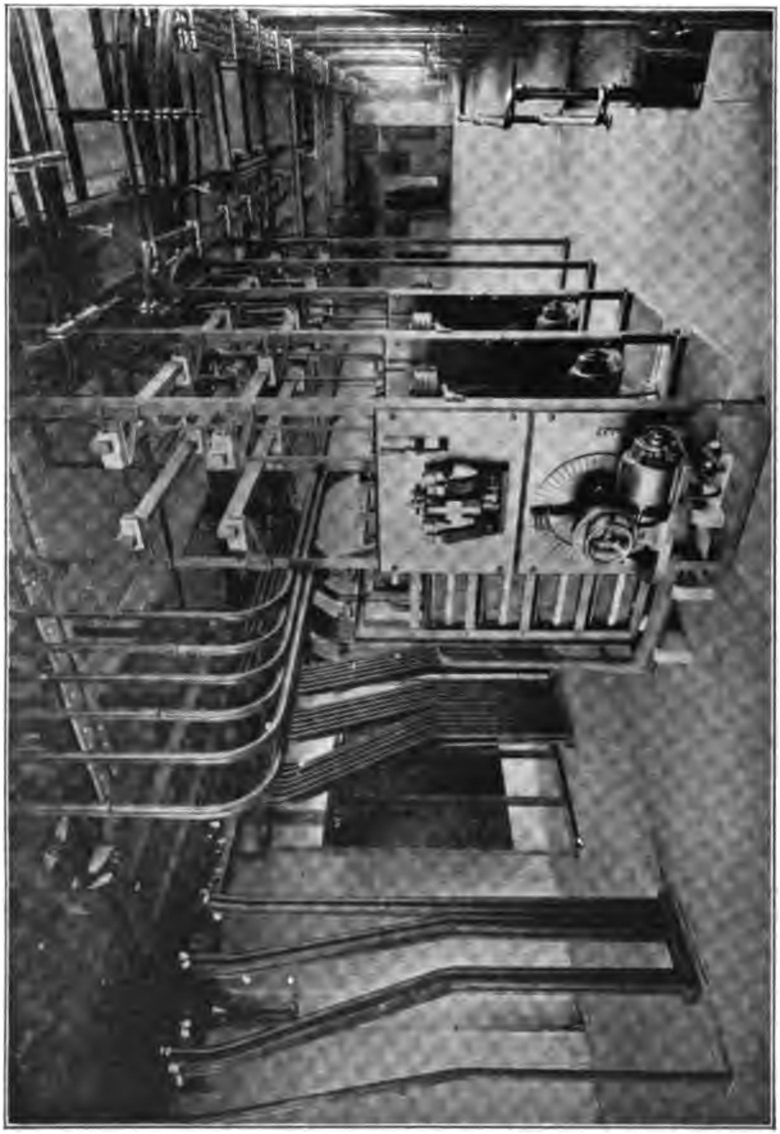


FIG. 256.—General View of Gallery showing Exciter Buses, Generator, Rheostat and Auxiliary Wiring. (Westinghouse, Church, Kerr & Co.)

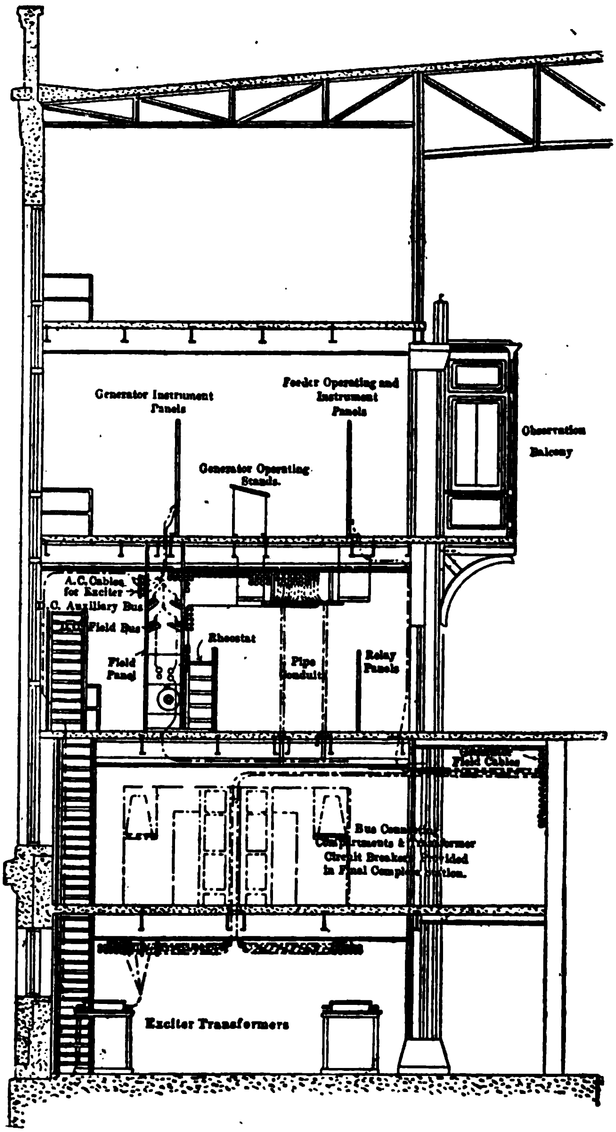


FIG. 257.—Cross Section through East End of Switchboard Gallery. (Westinghouse, Church, Kerr & Co.)

struments have a dull black finish. On the top of the generator bench are mounted all the necessary control switches and signal lamps for the generator oil switches, and also the control devices for the sectionalizing switches which will eventually be installed when the busbars are extended. Directly opposite the generator control panel is the corresponding instrument board to which the secondaries of the series and shunt transformers are connected. These leads are enclosed in fiber conduits. On the left side of the instrument panel is a board carrying three a.c. voltmeters, giving the e.m.f. in each leg of the busbars, and also a frequency indicator and two synchronizing lamps, one for each bus. To the right of the instrument boards there is a panel with one differential a.c. voltmeter, two synchroscopes, two synchronizing lamps and one a.c. ammeter indicating the current in the grounded neutral bus from the generators.

Fig. 256 shows how the rheostats, motors and electrically operated field switches are set up. Operation is from the bench. This equipment is installed directly under the operating room. (See Fig. 257.) The two last mentioned illustrations also show the mounting of the d.c. exciter busbars. The feeder board consists of three panels, each one of which controls two group switches and six feeder switches. At present only three of the latter are installed. The relays for the automatic oil switch control are on a separate panel on the first gallery near the field rheostats. An auxiliary panel which is set up in line with the feeder board controls the supply for the d.c. motors, for the station lighting and for the electrically operated oil switches. The exciter board also carries the necessary lever switches for the positive, negative and equalizer buses for the circuit breakers and instruments. A number of empty panels for future use are set up between the instrument and exciter boards. The disposition of the fiber ducts containing the control and instrument wires and of the generator field rheostats is shown in Figs. 252 and 253.

A complete signaling system is provided for communication between operating and engine rooms. It consists of a set of letter signals set up in the engine room which are illuminated by pressing push buttons in the operating room after the engineer's attention has been attracted by means of a signal

whistle. A set of return signals is set up in the operating gallery, and is actuated from the engine room, the operator's attention being attracted by a gong. Ready intercommunication is thus possible. A large synchroscope is placed over the signals in the engine room. Opposite each turbine there is an opal globe inside of which is a red, a white and a green lamp, and on a bracket outside of the globe a plain incandescent lamp. The lamps in the globe are used to denote the position of the weight upon the governor control of the turbine. The red lamp signals speeding, the white lamp dead center and the green lamp slowing. These signals are pilot indications of the position of the governor control weight, which is controlled from the operating room.

The other apparatus is used as follows: (The letters O.K., IN, OUT, S.B., and the numbers are illuminated on the board in engine room and in the operating room as stated above.)

1. To Cut in a Generator.

Operator.	Engineer.
(The number of the generator) IN-whistle.	(If O.K.) from the corresponding generator. IN-gong.

When the turbine is ready for load the engineer sounds the gong again. The operator connects the synchroscope and synchronizing lamp and when switched in parallel disconnects the synchroscope and synchronizing lamp, signaling O.K.

2. To Cut out a Generator.

Operator.	Engineer.
(The number of the generator) OUT-whistle.	(If O.K.) from the corresponding generator. OUT-gong.

Operator connects the synchroscope and synchronizing lamp.

When the generator is cut out the synchroscope commences to revolve and the synchronizing lamp to pulsate.

Operator signals O.K.-whistle and disconnects the synchroscope and lamp.

Engineer signals O.K.-gong.

All signals disconnected.

3. To Cut in a Turbine.

Engineer.	Operator.
From the turbine, IN-gong. Operation then continues as in first case.	From corresponding generator, IN (if O.K.)

4. To Cut out a Turbine.

Engineer.	Operator.
From the turbine, OUT-gong. The operation then continues as in second case.	From the corresponding generator OUT (if O.K.)

5. To Change Over.

First and second or third and fourth to be followed in sequence, depending upon whether the change is made from the operating room or from the turbine room. In case of trouble of such a nature as to require one unit to be cut out before the other is cut in, the operator or the engineer will show both signals as (number of generator)—OUT (number of generator)—IN and the whistle gives a long blast or the gong is sounded several times rapidly to call attention to the illuminated signs.

6. To Cut in an Exciter.

Operator.	Engineer.
(Number of the exciter) IN-whistle.	Brings the exciter up to speed, when ready signals O.K.-gong; from No. 1 turbine.
Operator cuts in and signals O.K.	
All signals disconnected.	

7. To Cut out an Exciter.

Operator.	Engineer.
(Number of the exciter) OUT-whistle.	O.K.-gong; from No. 1 turbine.
When exciter is cut out operator signals O.K.	
All signals disconnected.	

8. Stand-By Signals for Engineers.

Operator.	Engineer.
S.B.—(Number of generator) whistle.	S.B.-gong.
	Engineer signals O.K.-gong.
When over	
Operator signals O.K.-whistle.	
All signals disconnected.	

9. Stand-By Signals for Operators.

Engineer.	Operator.
From turbine, S.B.-gong.	Number of generator, S.B.-whistle.
When over	
Engineer signals O.K.-gong.	Operator signals O.K.-whistle.
All signals disconnected.	

10. When whistle is given one long blast, or gong is sounded several times rapidly it is to convey the meaning that the operation, whether a single or a double one, is to be performed as quickly as possible.

In starting a turbine the fields are built up gradually to give full voltage after the machine has attained its full speed. The generators are then synchronized and the main generator switch is thrown in. This switch is so wired that it cannot be closed until the synchronizing plug has been inserted into its socket in the operating board. In cutting out a machine, the load is taken off the generator by reducing the field excitation and then the main switch is opened. Afterward the field circuits are cut out. With the field circuits out, a turbine will continue to revolve about 45 minutes before coming to a standstill, but it will stop in about 10 minutes with the fields excited.

The switchboard operator gets his orders to cut current off or throw current on the high-tension lines from the sub-station at Woodhaven Junction. (See Chapter XXVIII.) He does not, however, change the switches until he is assured that the person giving the order has authority to do so.

60,000-VOLT STATION

Figs. 258, 259 and 260 (by courtesy of Mr. H. V. Hays) are the designs for a hydraulic power station to be located on a hillside. The generators are each rated at 7500 kw.

and 6600 volts, which is stepped up for transmission purposes to 60,000 volts through twelve 5000-kw. transformers. The entire switching plant is in a separate building. In the engine room there are only the operating switchboards mounted on a gallery and the field rheostats for the generators. The generator cables lead through the foundations and walls to the

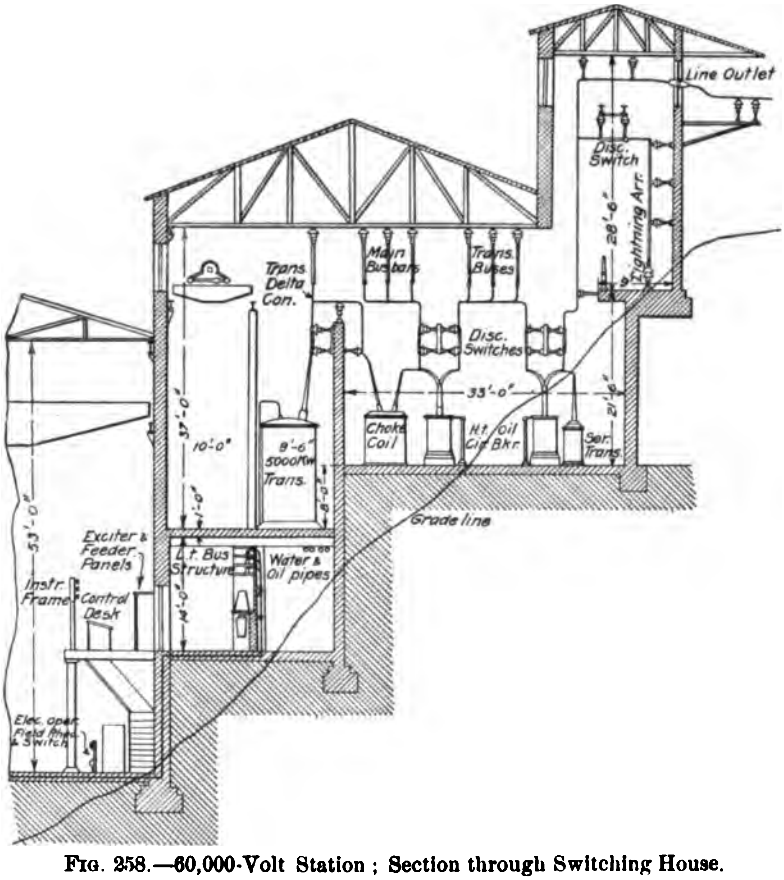


FIG. 258.—60,000-Volt Station ; Section through Switching House.

oil switches on the lower floor of the switching house, whence they lead to the 6600-volt busbars which are installed in the same room over the oil switches, being connected to the latter through disconnecting switches. (See Figs. 259 and 260.) On the next floor are the single-phase transformers, set up in compartments separated from each other. Each set of three trans-

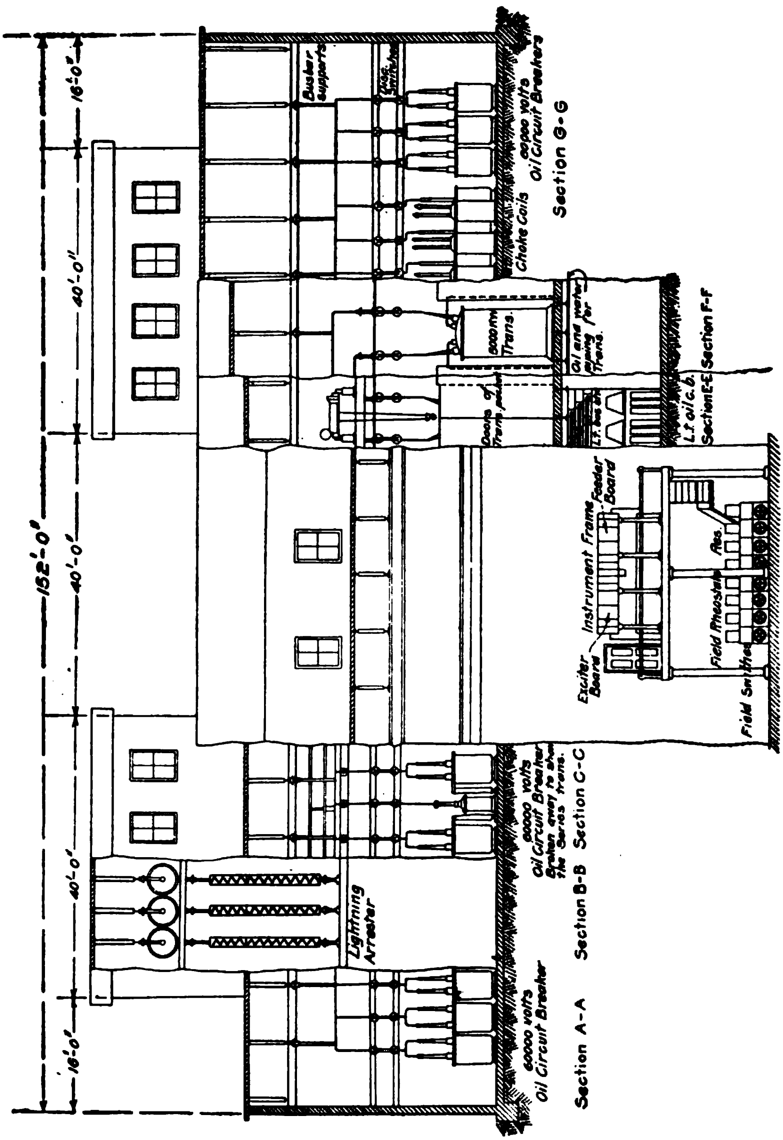


FIG. 259.—Sections taken on Lines A, B, C, D, E, F, G, of FIG. 260.

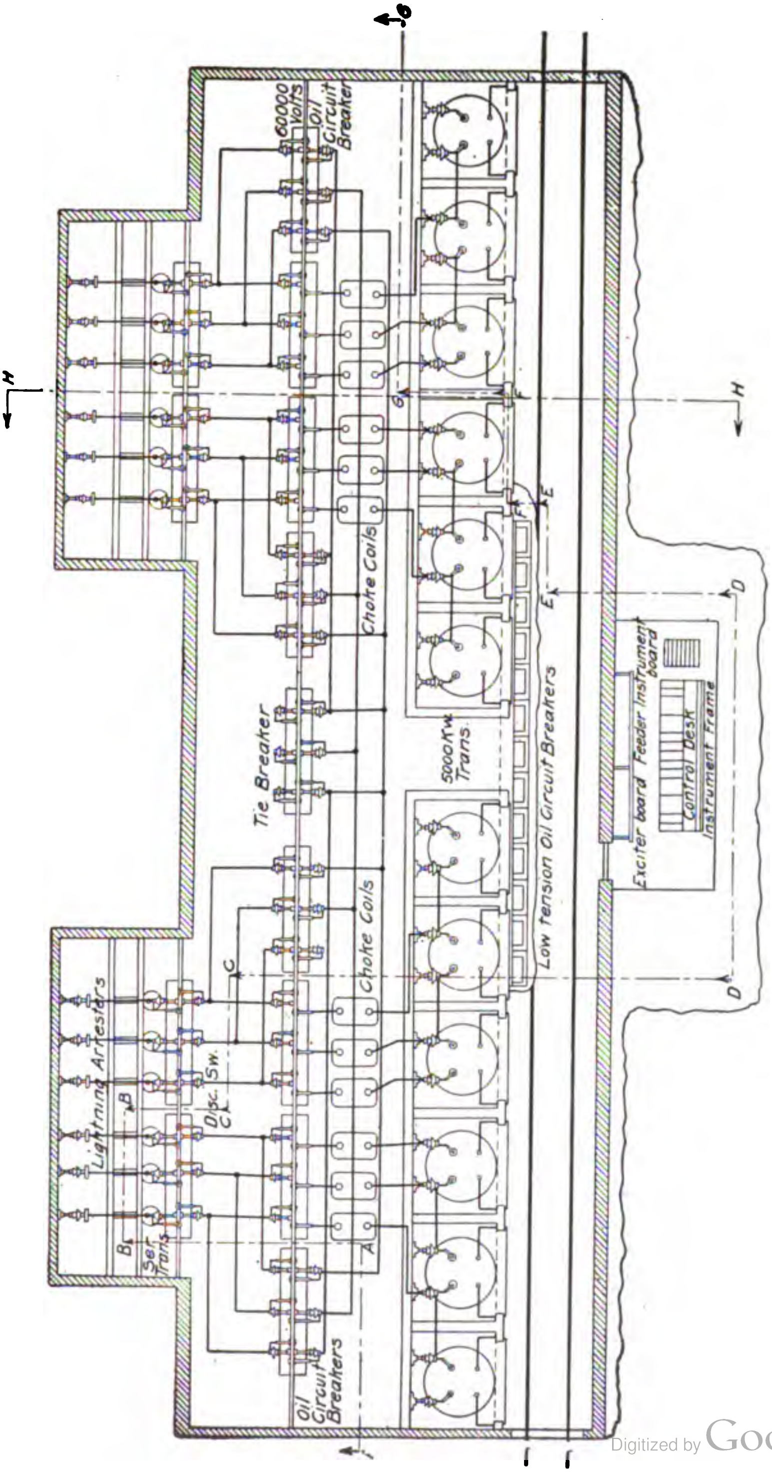


FIG. 260.—60,000-Volt Station: Plan View of Switching Arrangement.

formers is delta connected on the high and low-tension sides, the connection on the low-tension side being fed from the 6600-volt buses. A pair of disconnecting switches is inserted on the high-tension side of each transformer so that the apparatus can readily be disconnected, and the high-tension deltas are joined to reactance coils contained in separate oil vessels. From the coils the cables lead through oil switches and dis-

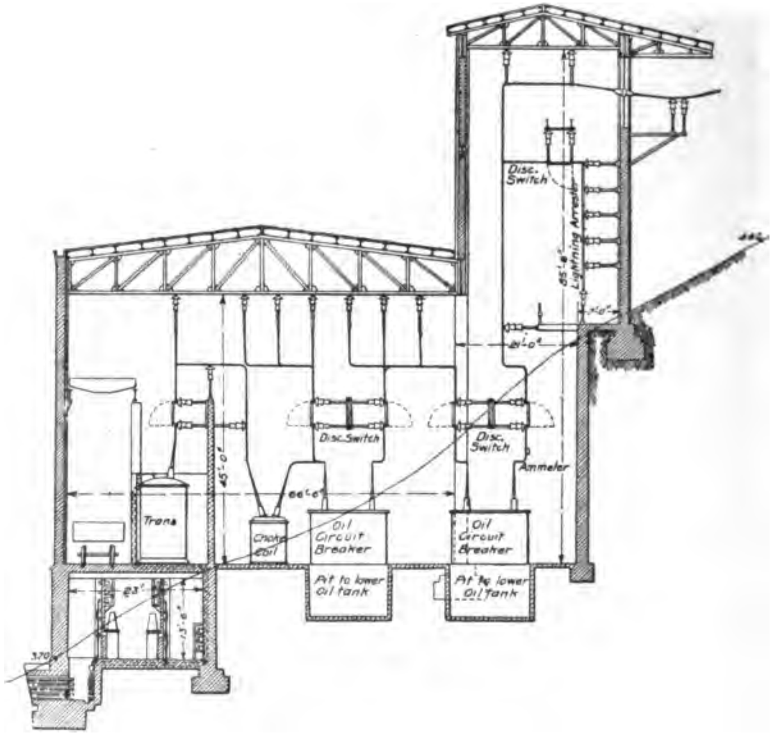


FIG. 261.—100,000-Volt Station: Cross Section Through Switch House.

connecting switches to a set of transformer busbars. There is a set of buses for each bank, which can be connected through oil switches and disconnecting switches to the main buses or to the outgoing feeders through a similar set of switches. The lightning arresters, line disconnecting switches and wall bushings for the line outlets are contained in two tower-like structures on the uphill side of the building. The high-tension oil switches are type G Westinghouse solenoid operated, and are set up in two rows. (See Fig. 260.) The end switches of the

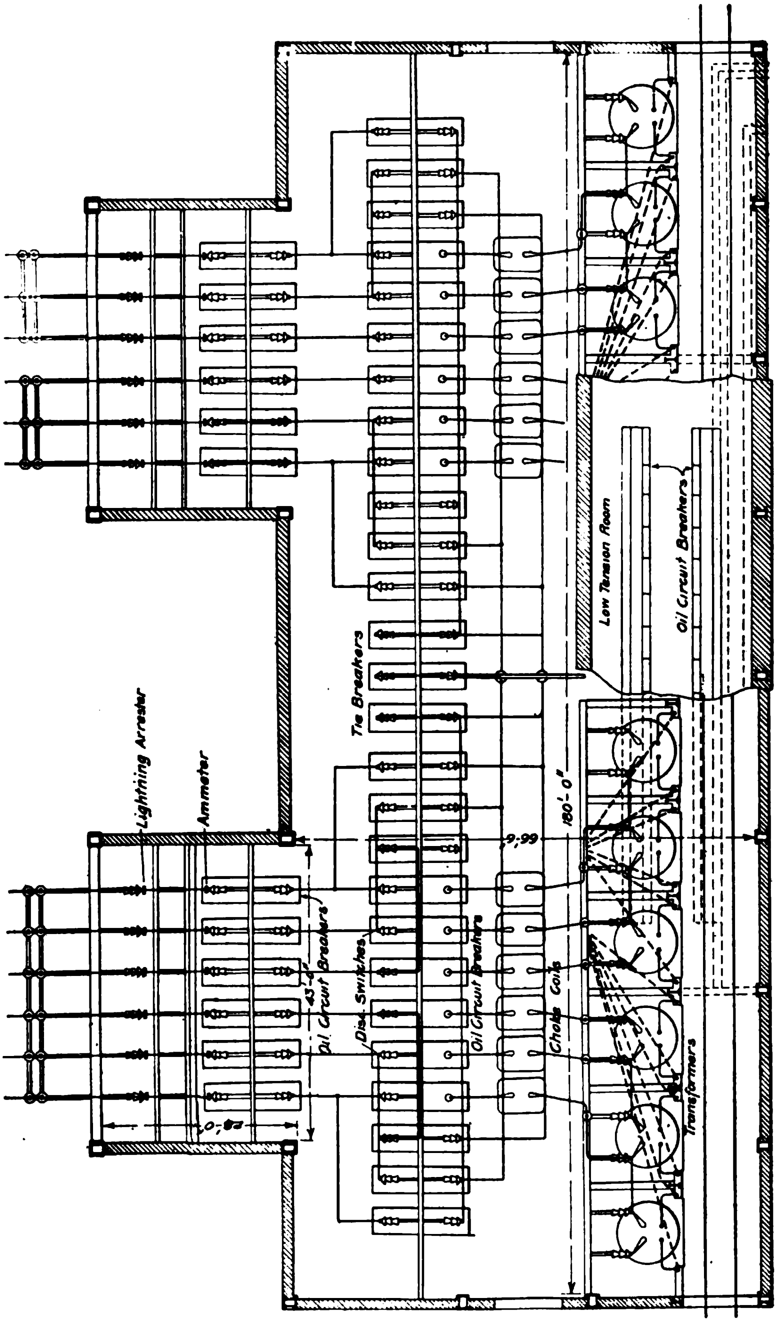


FIG. 262.—100,000-Volt Station; Plan View.

first row as well as the fourth switch from each end are for connecting the transformer buses to the main buses, and the second and third from each end connect the reactance coils to the transformer buses. The central switch is the bus sectionalizer. The first row therefore consists of nine oil switches each built up of three single-pole vessels. In the second row there are four oil switches, two in each tower, which connect the transmission lines to the transformer or main buses. Back of this row the instrument series transformers are set up. A traveling crane is provided to carry the large and heavy transformers up to the compartments.

On the gallery in the engine room the required switchboard is mounted. It consists of a generator control bench with vertical instrument board back of the bench and mounted on supports which also form the gallery railing. It also includes the feeder and exciter boards located near the back wall. The motor-operated field rheostats and the electrically-operated field switches are under the gallery. (See Fig. 259.)

100,000-VOLT STATION

Figs. 261 and 262 (by courtesy of Mr. H. V. Hays), are the cross section and plan for a hydraulic plant to have an ultimate rating of 50,000 kw. The leads of the 5000-kw., 6600-volt generators are joined to two busbar sets through selector and disconnecting switches. The former are type C Westinghouse, enclosed in cells in the same room with the bus compartments on the lower level of the switch house. The power house and adjacent switch house are built on a hillside similar to the 60,000-volt station described above. The twelve 400-kw., 6600 to 66,000-volt transformers are set up in insulated cells, and have a disconnecting switch on each side. At present the high-tension side is delta connected, and supplies 66,000 volts to the transmission lines. This will later be changed to a star connection to deliver 100,000 volts. The high-tension deltas are connected to reactance coils, and the transformers feed the main buses or the transmission line, with switching connections similar to those given for the previously described station. The high-tension oil switches are type L Westinghouse, and are arranged in two rows. Three single-pole vessels go to make up one unit.

CHAPTER XXVI

SUBSTATIONS

MODERN systems have come to assume such large proportions that it has become necessary to find some method of feeding other than those heretofore employed. Formerly the feeding capacity was increased by raising the d.c. voltage, by using boosters, or storage batteries with or without boosters, or by increasing the number of units in the independent generating stations. The method now almost universally adopted for large systems is to generate a high-tension alternating current in a central station and distribute it to the net through a number of substations. (See Chapter XXV.) The determination of how this method should be applied depends (1) upon the manner in which the system has expanded; (2) upon the kind of service, and (3) upon the reliability of the machines and apparatus:

1. The first point divides itself into three cases. (a) In the first case the system for which the generator station was originally designed has expanded to such an extent that isolated auxiliary plants become necessary to assist in supplying the excess demand in the various stations. This problem may be solved by dividing the systems into sections and supplying each section from its own independent station. This case arises most frequently in lighting or street railway systems in large cities. (b) A large system may also be formed by combining a number of independent, widely separated smaller systems, each having its own station. Suburban and interurban electric railways combined with street railways will be included under this head. (c) Electrifying railroads or designing large hydraulic plants for electrical transmission purposes, necessarily involves large service systems from the very start.

Lately the development of gas engine design has made such progress that it is safe to predict that in the future central

stations of enormous power will be built near the sources of coal supply to feed systems of wide radius.

2. The kind of consumption of electrical energy materially affects the ways and means for distribution and supply. Under this head there will be included: Street and interurban railways, or trunk lines, arc or incandescent lighting systems, and power distribution for motors, electrometalurgical or electrochemical purposes. (See Chapter XXIV.)

3. The method to be used for power distribution will depend upon the cost and reliability of machines for converting the energy from the central station into energy suitable for the desired purposes. It will also depend upon the adaptability of the consuming apparatus to the varying conditions to which it is subjected in service.

A study of the three above-mentioned considerations will lead to a determination of which course to pursue in order to obtain the best results with regard to cost, reliability and adaptability.

Three systems are then available: (1) Alternating-current central station with substations in which the high tension is stepped down and is converted by means of converters. (2) Alternating-current central stations with substations in which the converting to direct current is done by means of motor-generator sets. Transformer banks may be employed to step down the high tension when necessary. (3) Low-tension alternating-current feeder service. This requires either substation with transformer banks, or transformer banks alone located at the points of consumption. In some cases it becomes necessary to make use of motor-generator sets to change the voltage, frequency and phase of the high-tension supply.

Substations, like independent d.c. stations, supply districts in which they are located and in order to save copper they must be located at the load centers of these districts. Since they perform the same service as the former d.c. stations which they replace, and which are located at the load centers, it follows that the new substations may be located in the old buildings or on adjacent property. The equipment of the old stations is often used as a reserve or for peak loads. The number and size of the substations will naturally increase with the growth of the system and with the intensity of the load. The cost of

real estate, buildings, machines, operation and attendance will increase with the number of stations. It must therefore be considered whether it would be cheaper to use a large number of stations near together or a smaller number farther apart, but having a correspondingly increased power rating. Moreover, it must be remembered in this connection that substations with large units necessarily involve greater cost for reserve machines and for feeder systems. High service voltage allows greater distance between substations as noted in previous chapters. In direct-current service the line drop may be compensated and the efficiency of the machines may be increased by using storage batteries with boosters. (See Chapter V.)

SYNCHRONOUS CONVERTER SUBSTATIONS

Since synchronous converters first came into practical use in 1897 their development to the present day has tended to simplify a great many problems arising in large installations.

The direct-current voltage of a converter can be changed only by a change in the impressed alternating-current voltage, or by a change in the shape of the magnetic field set up by the field winding of the converter. For the first method, until recently, resistance coils and variable field excitation were in use; taps from the lowering transformers or from separate regulating tranformers and induction regulators, the last mostly in connection with shunt wound converters. More recently the method using a synchronous alternating-current booster mounted on the same shaft as the converter armature, and connected electrically in series with it, has been introduced. Another method of direct voltage variation based on the second of the two principles mentioned above, i.e., by a change in the shape of the magnetic field, has also been introduced recently. This is the "split-pole" or "regulating pole" converter, of which each pole is split up into two or more stations and the field form varied by varying the excitation of the different sections.

The use of resistance either in the lowering transformers or in special coils in connection with series windings on the field poles of the converter, is based on the principle that an increase in excitation causes the phase relation of the current to be leading with respect to the line voltage, and leading

current through resistance gives a rise in the resultant voltage. This voltage variation is automatic and therefore suits best for railway work in which the load fluctuation is large and rapid. On the other hand, the variation is obtained at the expense of a varying power factor.

The use of a synchronous booster involves the addition of an alternating-current generator of special characteristics to a standard rotary converter; the generator has the same number of poles as the converter, and the two revolving parts are carried by the same shaft. The booster, therefore, generates a voltage of the same frequency and phase as the induced voltage of the converter, and by properly proportioning its parts, the wave shape of the booster may also be made the same as the wave shape of the converter voltage. The booster armature is connected in series with the converter armature so that the voltage delivered to the converter armature is the sum of the line voltage and the booster voltage. The delivered voltage is varied by varying the field current of the booster —in one direction to raise, and in the other direction to lower the converter voltage.

In the split-pole converters the variation of the d.c. voltage is secured by varying the distribution of the flux under each pole, i.e., by varying the field form. For that purpose each pole, instead of being in one piece with one field coil, is made in two or three sections with two or three separate exciting coils.

It is a known fact that the voltage generated in any d.c. machine is proportional to the average value of the flux, or the average ordinate of the field form, between adjacent brushes. A variation of the field form which increases and diminishes the average ordinate will increase and diminish the generated voltage. This is done by means of the regulating poles with their separate exciting coils. On account of the presence of a.c. line voltage, the variation in field form must be accomplished without varying, to a corresponding degree, the wave form of the alternating-current voltage generated in the converter armature. The split-pole converter, therefore, consists of two essential elements; first, a means of varying the field form, and second, a means of eliminating the variation in alternating-current wave form resulting from the variation in the field form.

Step-down transformers used with converters consist either of a bank of three single-phase transformers or one three-phase transformer.

The advantages of polyphase transformers over the single-phase type are as follows:

1. The initial cost is less as the expense for material, labor and connections is less for one polyphase than for three single-phase devices.

2. The efficiency is greater as the loss due to the smaller amount of material is less.

3. It takes up less space and is lighter than the three single-phase transformers.

4. The cost of delta and star connections on high and low-tension sides is much less, since they call for less material and work. All connections are made inside of the transformer case, thus rendering them safer and simpler.

5. Transportation and installation costs are less.

The disadvantages are as follows:

1. Large cost for reserve units. Although the cost of a three-phase transformer is larger than that of a single-phase, the rating of the former is three times that of the latter. Where a large number of transformers is used, the relative cost of reserve is small. In some places in Europe it is customary to hold in reserve only the coils of the core type instead of the entire transformer, as these coils are easily replaceable. For the shell type the entire units must be used as reserves.

2. The system is seriously interrupted in case one of the polyphase transformers is disabled. This is the most serious disadvantage because in services with overhead lines which are exposed to atmospheric disturbances, a greater length of time is required to replace or repair a polyphase than for a single-phase transformer. If three single-phase transformers are delta connected on the high and low-tension sides it is still possible to use two of them at two thirds load without overheating in case the third is disabled. With the core type of polyphase transformer, the service is entirely crippled under these conditions, and with the shell type with delta connection, service may be maintained for only a short time until the trouble can be remedied. If the three single-phase are Y connected on one of the sides it is no longer possible to maintain

the service when one is disabled. In exceptional cases, however, when the Y connection is grounded and the system has a grounded return, partial service may be kept up.

3. Cost for repairs is larger.

With a bank of three single-phase transformers, any disturbance is confined to the phase in which it occurs, while with the polyphase arrangement, such disturbance easily spreads to the adjacent phases and involves larger repairs.

4. If self-cooled transformers are used, the power of the polyphase type is limited to 1500 kw., while with banks of single-phase almost twice this power may be employed. As a matter of fact, however, self-cooled transformers are seldom used over 1500 kw. Air-cooled polyphase are built for any desired power.

5. The difficulty of handling the larger number of taps for different voltage steps on one transformer is considerable.

On comparing the above advantages and disadvantages it is evident that three-phase transformers are applicable in large stations where the relative cost of the reserve is small, where there are sufficient handling facilities and where saving in floor space is essential. In transformers used for from 11,000 to 19,100 volts, the high-tension side is generally connected in delta, and with from 33,000 to 66,000 volts in Y with the grounded neutral. The secondaries are connected with the converters as follows: For two-phase diametrically, for three-phase Δ, Y or T, for six-phase diametrically, double delta, Y or T.

Transformers are built self cooled (H), air blast (AB), oil cooled (OC) or water cooled (WC), the manner of cooling depending upon the power and voltage.

For installation where initial cost is of less importance than minimum attendance and where very large units may not be asked for, the oil-cooled type of transformers is recommended. For plants requiring the largest size of transformers, either air blast or the water-cooled types must be used, if the choice depends on voltage, cheapness of water supply, fire risk and first cost.

In the air-cooled type, ventilators driven by induction motors must be furnished, and the transformers provided on the bottom with dampers must be set up over an air-tight chamber which receives the air blast from the ventilators. The diagram

in Fig. 263 gives the amount and pressure of air required for single-phase transformers. Approximately 150 cubic feet of air per minute are required for each kilowatt lost. For three-phase type the volume required is equal to that for three single-phase transformers each of one-third the power of the three-phase apparatus, but the pressure should be that required for one single-phase corresponding in power to the three-phase transformer. Turns in the air chamber should be avoided, and the cross-section should be such that the velocity of the air blast does not exceed 500 ft. per min. It should consist of smooth fireproof material and should be provided with drainage and

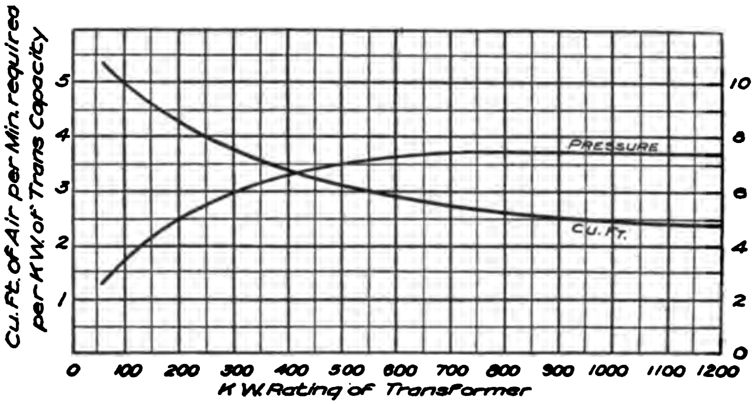


Fig. 263.—Diagram Showing the Amount and Pressure of Air Required for Single-Phase Transformers.

be easily accessible. Water and oil-cooled transformers have external piping to carry the cooling liquid to the apparatus. In the former type the water is forced to circulate, an extra pump being necessary for this purpose. The oil insulated types have the primary and secondary lead-terminals set on top of the transformer, while the air blast have the primary on top and secondary on the bottom. Traveling cranes must often be provided to handle the larger units, or the transformers are constructed with rollers or are handled with roller wagons on tracks.

With transformers having large ratios of transformation and operating on high voltage lines, there may occur, on the low-tension side, momentary voltages to ground, greatly in ex-

cess of the normal potential. These momentary increases in low-tension voltages are called "static disturbances," and in general are the result of a change in the static balance of the high-tension side and its connecting circuits. In transformers with a high ratio of transformation this static disturbance on the low-tension side may cause serious strains in the insulation. It is more serious in high ratio transformers because its insulation is less able to withstand it, the induced static voltage

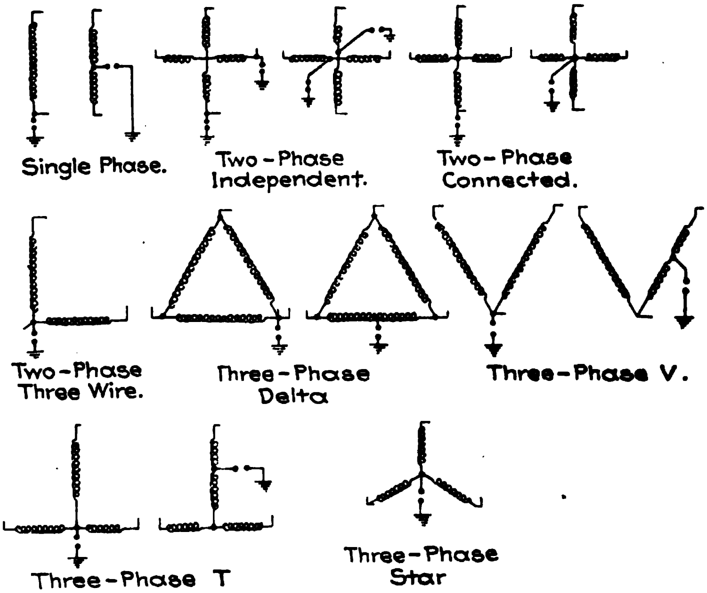


FIG. 263a.—Spark-Gap Connection to Transformer Banks of Different Transformations.

being independent of the ratio of transformation. A method of relieving this disturbance is to join a discharge gap between a middle or neutral point of the low-tension side of the transformer and the ground. Any voltage very much in excess of the maximum normal will cause a discharge to ground over the adjusted opening of the spark gap. The low-tension side will be thus tied to ground during such a discharge while at other times it is ungrounded. The commonly employed spark-gap connections to banks of transformers for different transformations are shown in Fig. 263a. The low-tension windings are only shown as the connection of the high-tension windings is in

general immaterial. One gap is used in all groups except that in two-phase independent circuits.

Substations may be classed with regard to their location in the high-tension net as:

Intermediate stations, and end stations. The former will lie between two or more other substations and the high-tension incoming lines feed the machines in the station and also the high-tension outgoing feeders which in turn feed the next substation. In case the intermediate station is located at a junction of several lines, and feeds a number of other substations it is called a distribution substation. End substations are the last stations on the system and may eventually become intermediate stations when the system expands. In case a load on a system is subject to shifting to certain sections during certain seasons, so that the load at these points requires additional substations, portable substations are made use of. A station of this kind consists of a car containing a complete substation equipment, which may be moved to any point along the tracks of the system and there joined to the high-tension line and the low-tension d.c. feeders. This form of substation is used only in railway service.

SUBSTATIONS WITH MOTOR-GENERATOR SETS

The great variety of component units which when mounted on the same shaft constitute a motor-generator set. enables such a set to meet very effectively the different requirements called for by railway, power and lighting service.

The two most important uses for motor-generator sets are for changing frequency and for delivering direct current. When a railway or power system fed by a high-tension current at 25 cycles is to be made to supply a 60-cycle lighting system a motor-generator set would be used consisting of a 25-cycle synchronous motor and a 60-cycle alternator. The arrangement of the machines must naturally be reversed if the lighting system is to feed the railway system. This use of motor-generators may be illustrated in another way, by considering two or more independent power systems of different frequency, whose supply is to be rendered interchangeable.

To drive single-phase railway motors it is often necessary to use motor-generator sets with 60-cycle three-phase synchronous

motors and 25-cycle single-phase generators. By this means the conversion is accomplished without unbalancing the three-phase system.

In designing motor-generator sets the speed must be so chosen that it will correspond to both frequencies and there must be taken into account whether or not the set is to be reversible. The most frequent use of motor-generators is to convert high-tension alternating current into low-tension direct current. Synchronous motors are preferred for this purpose since they are reversible. The power factor of the transmission line can be easily regulated by changing the field strength and the motor can be wound without difficulty for 10,000 volts or more. On the other hand an induction motor is of simpler construction, and requires a simpler switching arrangement and no exciter. The synchronous motor may be directly joined to the high-tension line, provided the transmission voltage lies below 15,000 volts. It might also be fed from a transformer bank when the line voltage exceeds the above value. The d.c. generator is of the ordinary type and is built for any required voltage.

Since a motor-generator set is employed for the same purpose as a synchronous converter the question arises which of the two methods is the better in any given case. The points which govern a selection are: (1) cost; (2) reliability; (3) adaptability; (4) efficiency; and (5) floor space.

In a paper read by Mr. E. W. Allen before the Association of Edison Illuminating Company are discussed the advantages and disadvantages of different apparatus for d.c. substation. An extract of the paper is given in the following tables and analysis of the figures. The machines taken for comparison are of the very latest type, the sychronous converter being of the split pole type, while the motor-generator sets are equipped with commutating poles.

The synchronous motor generator set having been selected in the accompanying table as a basis for the comparisons for the different types of sets in regard to their efficiencies, prices, floor space and weights, conclusions can be drawn as to the advantage in the use of one or of the other machine in cases at hand.

The values for synchronous converters and induction motor

TABLE OF COMPARATIVE EFFICIENCIES, PRICES FLOOR SPACE AND WEIGHTS*

Kw. Capacity	25 Cycles			60 Cycles		
	Syn. Mot. Gen. Set.	Ind. Mot. Gen. Set.	Syn. Convtr	Syn. Mot Gen. Set.	Ind. Mot. Gen. Set.	Syn. Convtr.
EFFICIENCIES						
300 Full load	84	+2.4%	+ 6.5%	86¾	−1.4%	+2.2%
¾ "	82¼	+2.1%	+ 7 6%	85	−2.0%	+2.1%
½ "	77	+4 0%	+12.3%	81¾	−2.7%	+1.0%
500 Full "	85½	+2.3%	+ 6.1%	87¾	−8 5%	+1.4%
¾ "	83¾	+2 1%	+ 7.7%	86	−1.1%	+1.2%
½ "	79½	+3 8%	+11.0%	83	−2.7%	....
1,000 Full "	87½	+ .3%	+ 4.8%	87¾	− 3%	....
¾ "	86	+ .6%	+ 5.2%	86	− .6%	....
½ "	82½	+1.7%	+ 9 4%	83	− .3%	....
2,000 Full "	88½	+ .6%	+ 4 5%	88½	− .3%	....
¾ "	85¾	+ .3%	+ 5.7%	86½	− .3%	....
½ "	82¾	+2.4%	+ 9.3%	83	− 3%	....
PRICE PER KW.						
300.............	$26 17	+ .6%	− 4.0%	$25 75	+ .3%	−3.0%
500.............	24.70	−1.4%	−11.7%	23.20	+ .9%	−2.0%
1,000.............	20.25	−3 0%	− .5%	19.45	+ .2%	....
2,000.............	19.10	−2.0%	+10.0%	18.10	+5.0%	....
FLOOR SPACE						
300...............	80	Same as Syn. Mot Gen. Set.	+13.7%	67	Same as Syn. Mot. Gen. Set.	+43.0%
500...............	122		+ 8 3%	110		+36.0%
1,000...............	136		+25.0%	140		....
2,000...............	440		− 8.4%	435		....
WEIGHTS						
300.............	50,000	−2.0%	−36.0%	48,000	−2.0%	−16.7%
500.............	68,000	−4 4%	−30.0%	65,000	−4.6%	−15.4%
1,000.............	98,000	−8.1%	− 5.0%	92,000	−3.3%	....
2,000.............	215,000	−7.0%	− 2.3%	212,000	−1.4%	....

* Electrical World. November 14, 1908.

sets are expressed in percentage of the corresponding values in the synchronous motor set. The sign preceding a figure denotes whether it should be added to or subtracted from the figure given on the synchronous motor. The analysis of the figures shows that the 25 and 60-cycle synchronous converters are superior in efficiency at all loads to either type of motor generator set, the difference being particularly marked at light load on the 25-cycle machine. The brush friction and windage constitute a relatively larger proportion of the losses in the 60-cycle converter, and its efficiency at light load only exceeds that of the motor generator set by a small amount. The in-

duction motor set is more efficient than the synchronous motor set at 25 cycles, but less efficient at 60 cycles. The difference in efficiency is considered in all cases when the cost of fuel for steam generation is an important factor. If water power is used this item may lose its significance.

With the exception of the 1500 and 2000-kw. 25-cycle units, the synchronous converters are less expensive in both frequencies than the motor-generator sets. In the larger sizes the 25-cycle induction motor sets are less expensive than either of the synchronous machines. The high cost of the 300-kw., 25-cycle induction motor set is due to the external starting devices, which constitute a relatively large proportion of the cost of the motor. The 60-cycle synchronous motor-generator sets are less expensive in all sizes than the induction machines listed at this frequency. If induction regulators are used with the older types of the converters for regulating the voltage, the advantage in the less cost of the converter is almost entirely eliminated.

The additional floor space required for converters with transformers must be considered in substations where floor space is valuable, such as in large cities. If the transformers can be located on a gallery a greater capacity in synchronous converters than in motor generator sets can be installed in a substation of a given floor space, inasmuch as induction regulators and series boosters are no longer necessary with the split-pole type of synchronous converters.

It is often necessary to increase the output of substations having limited floor space and headroom by the installation of larger units. Instances of this kind may be found in substations located in the basement of office buildings in large cities. The conditions here imposed have been successfully met by vertical synchronous converters. In Chicago, for example, the use of this type permitted the output of a substation to be increased 50 per cent. over that possible with any other machine available.

The weight of the motor-generator sets is, owing to the high speed, slightly less than that of the synchronous converters, with its accessories, the induction motor weighing less in both frequencies than the synchronous motor set.

Continuity of service can, with careful attendance, be ob-

tained from all three classes of machines. The excellent protection afforded by the use of speed limiting devices, reverse current relays and circuit breakers, practically eliminates the possibility of damage due to runaways or overloads.

Synchronous converters equipped with regulating poles can be used to obtain a wide range in voltage without materially increasing the cost over that required to give a lower range. The excitation of a split-pole converter can be controlled by means of an automatic regulator and the direct-current voltage kept constant even with wide variations in the voltage of the alternating-current supply. The regulator may also be adjusted to hold a constant load on the converter and cause storage batteries or other machines to carry fluctuations in the load beyond a predetermined amount. Advantage can be taken of this point when the energy is purchased from a transmission company whose rate of charge is based on maximum demand. In case induction and synchronous motors are used in the same system; the lagging current of the former can be compensated by overcompounding the synchronous motor, so that the resultant current from the central station will be in phase with the voltage. This ability to furnish a leading current to the line and improve the power factor and hence the regulation and output of the generating and transmitting equipment, constitutes one of the greatest advantages of synchronous over induction machines. The synchronous motor-generator set is therefore best suited in a system carrying a low power-factor load, as extra capacity for improving the power factor can be furnished at a small increase in the first cost and the same time the d.c. voltage may be easily and independently regulated by means of the shunt rheostat or by overcompounding the d.c. generator. Motor generator sets are well suited for lighting purposes. In Europe they are used almost exclusively and are preferred to converters even in d.c. railway service, as their converters, which have a frequency of 50 cycles, possess the same disadvantages as our 60-cycle machines for railway service.

Storage batteries are installed in the majority of lighting substations, and direct current starting is to be recommended in such cases for all three classes of machines. If d.c. cannot be obtained from such a source, a failure of the a.c. supply

will cause a complete shut down of the substation and require the starting of at least one unit from the a.c. side, after which d.c. will be available for starting the remaining units. All the machines described are suited for starting either from d.c. or a.c. side. The resistance in the secondary circuits of the induction machine limits the current at starting to a value considerably less than that required at full load.

Synchronous motors are started by means of starting compensators. Synchronous converters can be started from $\frac{1}{2}$ or $\frac{1}{3}$ and $\frac{2}{3}$ taps or the secondary of the transformers.

Twenty-five-cycle converters are better adapted to railway service than motor-generator sets, as they respond more readily to fluctuations in load and possess a greater overload capacity. Those equipped with regulating poles are superior to all types of machines listed in those qualities which ordinarily govern the selection of low frequency substation apparatus with the exception in cases where precise voltage regulation is necessary. Sixty-cycle synchronous converters are more efficient than either type of motor-generator set, but afford a relatively small margin for correcting the power factor of the system. this last is the reason that synchronous motor-generator sets are more generally used at the higher frequency. Sixty-cycle induction motor-generator sets are the least efficient of all and as they possess the added disadvantage of lowering the power factor of the line, are seldom recommended for lighting and power substations.

In practice motor-generators are used for feeding the two outer wires in three-wire systems, or for feeding all three wires in three-wire systems. In the former case a single generator will be used coupled to a synchronous motor, and in the latter two generators driven by one induction or synchronous motor are required. For railway service there is used one 600-volt generator with an induction motor. Motor-generators are also used as exciter sets, booster sets, balancer sets in three-wire systems, or as charging sets for storage batteries.

TRANSFORMER SUBSTATIONS

A system employing high-tension alternating current, possesses not only the advantages due to high tension, but also those resulting from the use of alternating current.

In America as well as in Europe alternating-current railway service is essentially single-phase, although in a few inclined railways such as the Jungfrau, Gornegrat and Engelberg and the experimental road Berlin-Zossen, three-phase is used. Single-phase is preferred on account of its simplicity and especially since the new types of single-phase motors have done away with the former lack of good motors with which single-phase current could be used.

In the following paragraphs there will be pointed out the various methods employed in practice for generation and distribution of alternating current.

1. Single-phase current is generated, and is fed to the overhead lines directly as such or through transformers.

2. Three-phase current may be generated to supply a motor-generator set from which the required single-phase is obtained.

3. The single-phase railway net may be joined through transformers to one leg of the three-phase transmission line.

4. The three legs of the three-phase line are connected to transformers and are made to supply separate portions of the system.

5. The central station may be located at the center of the system and generate two-phase, each leg supplying energy to half of the system.

6. The three-phase line may be connected to three-phase-two-phase transformers which feed separate sections of the line. Each section is supplied from two adjacent substations.

1. In this case it must be remembered that no synchronous converters, self-starting synchronous motors or induction motors starting under load can be fed from the line. This system is therefore applicable exclusively to railway service and especially for trunk lines using a current of 15 cycles which is subject to no other kind of load.

Single-phase generators are difficult to regulate. They are heavier and more expensive and operate at lower efficiency. The same considerations apply to single-phase transformers. They nevertheless afford simpler generation and distribution and therefore the switching arrangements are cheaper. When transformers are required, one in each substation will suffice. In that case one terminal of the low-tension side of the transformer is grounded and the other is connected to the overhead line.

2. If three-phase is generated, synchronous converters may be used to feed motors and lighting systems. A single-phase railway net supplied from motor-generators does not subject the primary transmission line to unbalanced loads, which is one of the greatest advantages of this system. The set can be used as a frequency changer, with the motor run by a 60-cycle current and the generator supplying current at 25 cycles. Another advantage is that it can be set up either in the central station or in the substation. In the former case, both the primary and secondary distributing nets are single-phase, while in the latter, the primary is three-phase and the secondary single-phase.

3. Although the system in which a single-phase railway net is fed from one leg of a three-phase system admits of the use of converters and synchronous motors on all three legs of the circuit, it nevertheless causes considerable unbalanced loading, so that the rating of the starting machines is reduced by from 30 to 50 per cent. The generators themselves will have the same disadvantages as the single-phase machines, and moreover will have only two-thirds the rating which they would have in a balanced three-phase system. In this case both the primary and secondary distribution are single-phase.

4. When the length of the overhead line may be divided into three parts or any multiple of three, then the sections are fed singly from the separate legs of the three-phase circuit. Any two adjacent substations will feed the intermediate section from the same phase, so that two transformers in each substation will be necessary to care for the service. The three-phase net is balanced subject to the condition that the sections are equally loaded. As this requirement cannot be met, this method of generation and distribution is open to the same objections noted above under 3.

5. In this system, like in the one described above, the two-phase line is balanced only as long as the two sections are loaded equally.

6. In this last system, the three-phase is supplied to each substation where three-phase-two-phase transformer bank (consisting of two transformers) is operated. The secondary delivers two-phase current and the phases are separated so that each feeds a portion of the overhead line. As a rule, adjacent

substations feed the intermediate section from the same leg, as in case 4. The system is balanced only when the line is correctly subdivided and when the loads in the various sections are equal.

In considering the relative merits of substations, however, it is found that the two systems differ widely.

Consider a single-phase system with substations for stepping down to a lower supply voltage or for supplying single-phase from three-phase e.m.f. Each of the substations must be equipped with one or more transformer banks which, when compared to the equipment for converter substations, cost considerable less. The cost of buildings, switching equipment and attendance is also a great deal less than for the converter stations. Since the voltage in the supply lines for this kind of system is higher than that ordinarily used with direct current, a greater line drop becomes admissible, when it follows that the substations may be placed farther apart. This naturally results in a less number of such stations and in greatly reduced total cost.

In single-phase systems the distance between substations and the cross section of the overhead lines for a given service voltage and drop are interdependent. The relation between these quantities should be such that the greatest possible economy is obtained, that is, the least weight of copper with the least number of substations. In this connection the following points should be taken into account.

1. The line drop should not be sufficient to affect the efficiency of the car service or the lighting of the cars.

2. Reserves must be kept on hand in each substation for replacing disabled apparatus. The rating of the transformers must be large enough to enable them to carry not only the maximum overload but also the combined normal load of their own section plus that of the next adjacent section. (In case of breakdown of an adjacent transformer station.)

3. The overhead line should have neither too small nor too large a cross section. The latter specification is to avoid unnecessarily heavy suspension.

4. A less number of substations decreases the number of danger points where the connections to the high-tension line are made.

* DATA ON SINGLE-PHASE ELECTRIC ROADS IN AMERICA.

Name of Road.	Length (Miles) of Line, Electric.	Equipment. Cars. No.	Cars. Motors.	Locomotives. No.	Locomotives. Motors.	Type of Control Used.	Line Character. Voltage.	Line Character. Cycles.	Electric Service Started.
WESTINGHOUSE.									
Indianapolis & Cincinnati Traction Co.	116	25	4—100	0	....	Unit sw.	3300 550	25 D. C.	Dec. 1904
Westmoreland Traction Co.	6.6	4	4— 50	0	....	Hand	1200	25	March 1905
San Francisco, Vallejo, Benecia & Napa Valley Ry. Co.	34	2 8	4— 75 4—100	0	....	Unit sw.	3300	25	June 1905
Atlanta Northern Traction Co.	18.2	8	4— 50	0	....	Hand	2200	25	July 1905
Warren & Jamestown Street Ry. Co. ..	22.5	6	4— 50	0	....	"	3300	25	August 1905
Long Island Railroad Co.	5	6	2 — 50	0	....	"	2200	25	Sept. 1905
Spokane & Inland Ry. Co.	115	21	4—100	6 8	4—150 4—175	Unit sw.	6600 550	25 D. C.	Nov. 1906
Erie Railroad Co.	34	6	4—100	0	....	"	11000	25	Dec. 1906
Fort Wayne & Springfield St. Ry. Co. .	21.5	4	4— 75	0	....	"	6600	25	Jan. 1907
Pittsburg & Butler St. Ry. Co.	33	11	4—100	0	....	"	6600 550	25 D. C.	May 1907
New York, New Haven & Hartford R.R. Co.	22	0	....	35	4—250	"	11000 600	25 D. C	July 1907
Windsor, Essex & Lake Shore Rapid Ry.	28	5	2—100	0	....	Hand	6600	25	Sept. 1907
Grand Trunk R.R. Co. (Sarnia Tunnel)	3.5	0	....	5	3—240	Unit cont.	3300	25	Under constr.
Visalia Electric Ry. Co.	23	4	4— 75	1	4—125	"	3300	25	"
Chicago, Lake Shore & So. Bend Ry. Co.	78	24 4	4—125 2— 75	0	....	Unit sw. Hand	6600 575	25 D. C	"

Denver & Interurban Ry. Co.	46	10	4—125	0	....	Unit sw.	11000 575	25 D. C.	"
Hanover & York St. Ry. Co.	20	5	4— 75	0	....	"	6600 575	25 D. C.	"
Shore Line Electric Ry. Co.	12	4	4— 75	0	....	"	6600	25	"
Maryland Electric Ry. Co.	24	9	4—100	0	....	"	6600	25	"
General Electric Co.									
Schenectady Ry. Co. (Ballston Div.)	15.5	.....	4— 75	0	....	K	2200 600	25 D. C.	In operation
Bloomington, Pontiac & Joliet Ry. Co	19	2	4— 75	0	....	K	3300	25	"
Toledo & Chicago Ry. Co.	43	7	4— 75	0	....	K	3300 575	25 D. C.	"
Milwaukee Electric Ry. & Light Co.	59	11	4— 75	0	....	M	3300 575	25 D. C.	"
Central Illinois Construction Co.	80	20	4— 75	1	4—150	M	3300 575	25 D. C.	"
Richmond & Chesapeake Bay Ry. Co.	15	4	4—125	0	....	M	6600	25	"
Anderson Traction Co.	20	3	4— 75	....	....	K	3300 575	25 D. C.	"
Washington, Baltimore & Annapolis Ry. Co.	60	21	4—125	0	....	M	6600 575	25 D. C.	Under constr.
New York, New Haven & Hartford R.R. Co	8	4 2	2—125 4—125	....	....	M	11000	25	"
Shawinigan Ry. Co.	....	0	....	1	4—150	M	6600 600	30–15 D. C.	"

* "Single-phase Electric Railways." M. N. Blakemore, Electric Journal, Feb. 1908.

The preceding table gives the length, number of cars and service voltage of systems employing single-phase current on the entire line or on only a part of the system. Two values in brackets in the voltage column indicate that part of the service is single-phase and part direct current. The latter is generally employed in cities while the former is used on the suburban and interurban lines.

MISCELLANEOUS SUBSTATIONS

Another type of substation contains only storage batteries which are used to feed the lines. A station of this sort is usually located in an annex to a central station or to a converter substation, or it may be housed in a building of its own. This depends upon whether or not the battery is to be used as a reserve or equalizer for the converters, or for feeding the line directly, equalizing the load in the transmission line or for compensating the voltage loss. Equalizing and compensating tend towards saving in copper and raising the efficiency of the line. Line batteries are connected to the line directly as floating batteries; that is the charges and discharges are made to depend upon the suddenness of the load fluctuations. If the fluctuations are not sudden enough or if a more sensitive regulation is required, the action of the battery is regulated by a booster located in the central station or in the battery substation.

On their electric zone The New York Central and Hudson River Railroad employs two circuit breaker houses between each two adjacent substations which are fed from the nearest substation. They are used to assist in governing the supply for the third rail. Each house contains six circuit breakers, one for each of the connections to the four third rails, one for the auxiliary feeders, and one for a spare in case of failure of the other five. The circuit breakers open automatically on overload but they can also be opened or closed from the nearest power substation. Pilot lamps in these stations indicate whether the breakers are opened or closed.

Lightning arrester houses are placed where underground feeders change to overhead lines. They contain the necessary lightning protective devices, reactance coils and disconnecting switches.

CHAPTER XXVII

TYPICAL SUBSTATIONS

LONG ISLAND R. R.

In the following description is given an extract of an article by W. N. Smith, published in *Street Railway Journal:* The high-tension transmission system of the Long Island Railroad is shown in Fig. 264. From the central station in Long Island City five feeders run out in an 18-duct conduit line to Dutch Kills Street, and thence overhead on a line of steel poles to the distributing substation at Woodhaven Junction. A branch line of three circuits runs westward from here to East New York substation, two circuits running thence to Grand Avenue substation, all these being run in underground conduits. To the east of Woodhaven Junction there are two circuits, run underground to Dunton where the transmission is changed from underground to overhead, continuing eastward overhead on steel poles to Rockaway Junction substation. The branch circuits from the Rockaway Junction to the portable substation terminal buildings at Belmont Park and Springfield Junction are carried overhead on wooden poles. An additional feeder runs out underground from Woodhaven Junction in the same direction, to the repair shop at Morris Park. Southward from Woodhaven two circuits are carried overhead to Hammel substation.

The table on page 368 gives the present and ultimate equipment of the above mentioned stations.

The converters used in the substations are of the Westinghouse type, each provided with a starting motor mounted on an extension of the base of the converter. The 1000-kw. converters are rated to deliver 1600 amp. at 625 volts and 1667 amp. at 600 volts. The three-phase e.m.f. at the alternating end is approximately 370 volts for 625 at the direct-current end. These machines possess 8 poles and operate at 375 rev. per min.,

* "Long Island R. R. Substations," *Street Railway Journal*, June 23, 1906.

Station.	Rotary Con-verters. kw.	Trans-formers. kw.	Boosters. kw.	A. C. Feeders.	D. C. Feeders.
Grand Avenue:					
Present installation......	3—1000	9—375	....	2	5
Ultimate capacity.......	5—1500	15—550	....	4	11
East New York:					
Present installation......	3—1000	9—375	....	5	6
Ultimate capacity.......	4—1500	12—550	....	12	16
Woodhaven Junction:					
Present installation......	3—1500	9—550	....	12	10
Ultimate capacity.......	6—1500	18—550	....	18	18
Rockaway Junction:					
Present installation......	2—1000	6—375	....	4	6
Ultimate capacity.......	4—1500	12—550	....	11	16
Hammel:					
Present installation......	2—1000	6—375	2—162	2	6
Ultimate capacity.......	5—1500	15—550	2—162	5	13
Valley Stream............	....	....	....	....	....
Two portable substations:					
Each equipped..........	1—1000	3—375	....	1	1

corresponding to a frequency of 25 cycles per second. The 1500-kw. converters are rated to deliver 2400 amp. at 625 volts or 2500 amp. at 600 volts. They have 12 poles and run at 250 rev. per min. Both types have compound field windings with the shunt winding arranged for self-excitation.

The transformers used for the converters are of the air-blast type. Those for the 1000-kw. converters are grouped in banks of three 375-kw. transformers to one converter. For the 1500-kw. machines they are in groups of three 550 kw. each. The high-tension winding is designed for a normal e.m.f. of 12,000 volts, with taps arranged to enable other voltages to be utilized down to 10,000 volts. The low-tension winding is designed to carry 400 volts normally, with taps which will enable other voltages to be taken off down to 340 volts. The high-tension terminals are at the top of the transformer, and the low-tension in the bottom.

In each station there are four sets of auxiliary transformers which supply energy for the following purposes: (1) To the converter starting motors. (2) To the motors driving the booster-generators and their exciters. At Hammel station these transformers are made large enough also to drive converter starting motors at the same time. (3) For driving the

transformer blower motors and an induction motor-generator set used to charge the small auxiliary storage battery that supplies energy for the electric switch control system. (4) For house lighting.

At substations Nos. 1, 2, 3 and 4 where there are no storage batteries, a group of three transformers is employed to

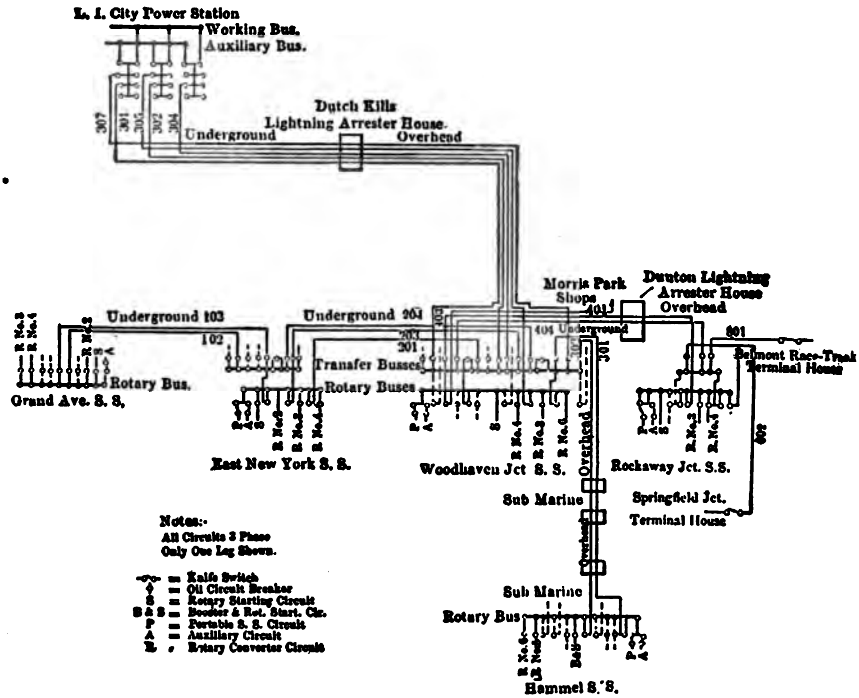


FIG 264.—Outline Diagram of Feeder Circuits.

furnish energy for the starting motors of the converters. These are rated at 50 kv-amp. each, the bank being able to start up and synchronize three 1500-kw. converters simultaneously. They are of the oil-insulated, self-cooling type and reduce the three-phase 25-cycle current from 12,000 volts to 400 volts. They are placed in a row on the main floor and are connected to the main bus by an automatic oil switch, electrically operated from the main control stand.

At substation No. 5 where a storage battery is employed that involves the use of two 162-kw. booster-generators each driven by a 235-hp. induction motor, there is provided a bank of three 200-kw. air-blast transformers. These are sufficiently large not only for operating the battery booster under maximum conditions of load but also for simultaneously starting one converter without dropping the secondary voltage of the transformers sufficiently to affect the booster regulation. These transformers are set on the main floor over the air ducts for the main transformers and in line with the latter.

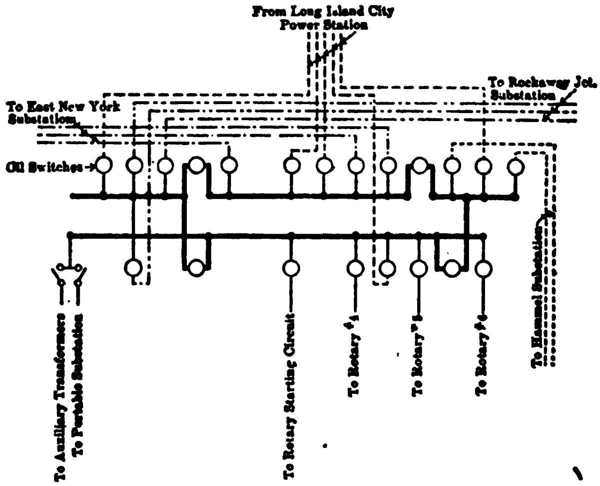


FIG. 265.—Arrangement of Connections to High-Tension Buses at Woodhaven Station.

The seven 0.5 kv-amp. transformers are provided for the blower motors and the induction motor which operates a small booster-generator used for charging the auxiliary storage battery that furnishes energy for the electrically operated switch control system. At Woodhaven Junction they are of 10-kw. rating. These transformers are of the oil-insulated type, and the transformation is from 12,000 volts to 400 volts.

The Woodhaven Junction station and those in East New York and Rockaway Junction distribute alternating current to feeders supplying the outlying substations near the terminals

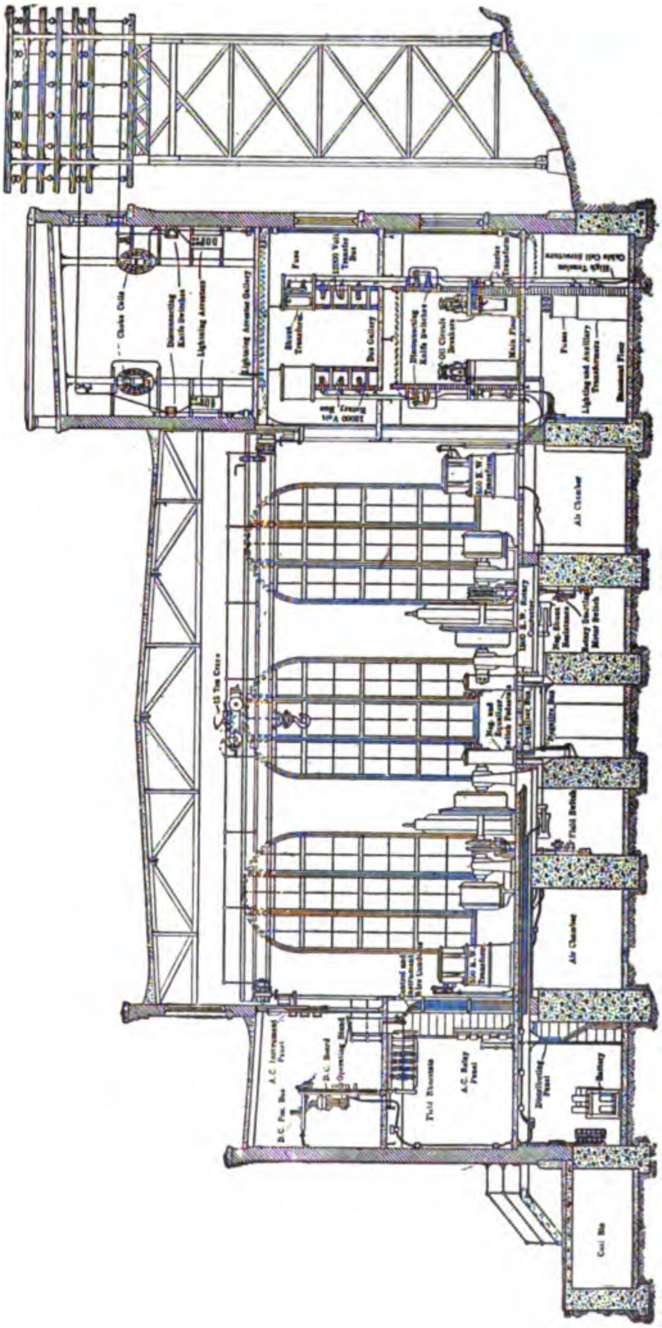


FIG. 266.—Elevation of Woodhaven Junction Substation, Long Island Railroad. (Westinghouse, Church, Kerr & Co.)

of the railway system. For this purpose they are equipped with two sets of buses, one called the transfer bus and the other the working bus, the former giving flexibility in shifting feeders among all the substations. The converter or working bus in each station receives energy directly through feeders, and independently of the transfer bus in that particular station. This enables high-tension energy to be passed through an intermediate substation to one or more beyond, independent of operation of apparatus in the former.

Fig. 265 illustrates the high-tension connections at Woodhaven substation and shows how the three outgoing branches of the feeder line each receive energy through a separate section of the transfer bus in that station, each section having an independent feeder on the main trunk line coming from the power station. The transfer bus is sectionalized by non-automatic oil switches so that all branches can be run separately or together as desired. By means of tie switches the converter bus can be coupled to either of the three sections of the transfer bus. The other two intermediate substations have a similar equipment but it is somewhat simpler, as less apparatus is required. In the ultimate installation it is planned to have main feeders run directly from the Long Island City power station to each of these three principal substations. The feeders now connecting to these transfer buses will then be available as relays.

At substations Nos. 1 and 5 the only bus needed is that required for the operation of the converters.

The plan and cross section of the Woodhaven station are shown in Figs. 266 and 267. A side track enters the station and enough space is provided to permit the entrance of a portable substation which can be coupled with the apparatus at the station if required. The feeders from the central station run to a tower-like structure in one end of the station where the lightning arresters, reactance coils and disconnecting switches are located. The arresters are of the Westinghouse low-equivalent type mounted on marble panels which are carried on steel angle iron framework. The three arresters on the three legs of the high-tension circuits are separated by barriers of asbestos lumber. The arresters are all provided with knife switches so that they can

readily be disconnected. There is a reactance coil in series with each main circuit mounted near the top of the steel framework. The arresters are mounted on special porcelain insulators and the use of wood is entirely dispensed with in the lightning arrester gallery, thus insuring fireproof construction. The openings in the side through which the cables enter are 18 in. square, enclosed by two glass plates 0.375 in. thick and separated 5 in., having 2.5-in. holes in the centers through which the cables and feeders pass, without touching the glass. Access of rain or snow through the openings is prevented by a thin brass disk about 2.5 in. in diameter which is fastened upon each cable between the two glass plates. Standard straight line insulators are used for supporting the bare wire inside of the building.

From the gallery the cables are led down the main wall to the basement whence they are run to the respective oil switches on the machine room floor. These switches are set up in two rows, that nearer the outside wall containing all of those belonging to the distribution system for the other substations and the other containing the switches for station use. From the feeder oil switches cables are led to the working and transfer buses on the bus gallery. From the latter they run through disconnecting and oil switches to end bells for the underground cables in the basement or to the reactance coils and lightning arresters in the tower for the overhead lines. From the working buses, on the other hand, the cables pass through disconnecting and oil switches to the high-tension delta of the transformers. The positive cables of the machine are led to the positive busbars on the d.c. board on the operating gallery; whence the feeding of the third rail is controlled. The outgoing d.c. feeders are taken out underground in tile ducts. In Fig. 265 there are indicated the mounting of the negative and equalizer buses, the field switch, and the shunt resistance in the foundations of the machines, and also the pedestals with the negative and equalizer switches on the machine room floor near the machines. On the operating gallery are set the switchboards controlling the a.c. feeders, the bench and instrument boards for the converters, and as mentioned above, the panels for the d.c. side of the machine and for the d.c. feeders.

The a.c. control apparatus consists of two groups, one taking care of the oil switches for the incoming feeders from power station to transfer bus, for the bus section switches of this set of buses, and for the outgoing high-tension feeders from the transfer bus to the substations. The second group controls the feeder from the power house to the working or converter bus, the switch connecting the transfer and converter buses and the switches joining the main transformers for the converters with the working bus. The first group has its controlling apparatus on a switchboard consisting of three panels, each of which has provision for mounting six 500-amp. a.c. ammeters, eight controllers for the oil switches with eight pairs of signal lamps. The second group is mounted on a separate bank of control benches with instrument panels, which are set up so as not to obstruct the operator's view over the station. Going from left to right the designation of the control and instrument panels on the bench and overhead framework is as follows:

1. Two converter bus connecting switches. These connect the converter bus with the transfer bus.

2. Alternating-current feeder direct from power station to converter bus.

3. Blank panel reserved for booster in case of storage battery installation.

4. Switches connecting the converter bus with transformers supplying converter starting motors (and booster motors when installed).

5. Blank panel for future converter.

6, 7, 8. Panels for converters installed.

The oil switches for manipulating the 12,000-volt current are three-pole type C Westinghouse. Their normal carrying capacity is 600 amp., but they can handle a short-circuit of a maximum kilovolt-ampere rating equivalent to a generator rating of 33,000 kw. All oil switches are automatic except those used for connecting the sections of the transfer bus. The control apparatus by means of which the electrically operated oil switches are worked from the control stand consists of a circuit supplied by a storage battery whose current is conveyed to the two closing coils and one tripping coil of each oil-switch. The control circuits are closed either by a controlling switch

on the bench, or if control is automatic by the time-limit relay which is actuated from a series transformer in each high-tension circuit. The panel with the relays is on the machine-room floor under the operating gallery.

The high-tension busbars each consists of three sets of bars of rolled copper mounted on porcelain pillars and carried in closed compartments placed one above the other in a structure of yellow pressed brick with alberene stone slabs separating the three tiers. The holes by which the taps enter and leave the compartments are made through alberene stone slabs bushed with heavy porcelain insulating bushings. Where the busbars are sectionalized the compartments in the same tier are completely divided off by stone slabs. The shunt transformers are in separate closed compartments on top of the bus structure. On the back of each of these structures is built a set of vertical septums to separate the cables that enter and leave the structure to tap the busbars. The septums are continuous with those in the upward extension of the back walls of the oil switch structure.

The air-cooled transformers are set up over air chambers in two rows on both sides of the machine room. Two ventilators supply the chambers, operated by 9.8-hp. motors. The ventilators run at 480 rev. per min. and deliver 18,000 cubic feet of air per minute at 70° F. against a maintained pressure of 1 oz. per square inch. All disconnecting switches are separated from each side by asbestos barriers. The series transformers for the instruments and relays are mounted in compartments in back of the oil switches.

The arrangements in the other stations are similar to the one described above but are somewhat simpler, since there are less machines and instruments and since no lightning arresters are necessary with the underground lines.

Hammel station differs from the others in that it is provided with a storage battery which is used as a regulator for the converters, though provision is made in the design of the other substations for their ultimate installation. The battery itself comprises 300 elements of the Electric Storage Battery Company's chloride accumulator, each element containing 55 type R. plates in regular service. At the temperature of 70° F. they have the following ratings:

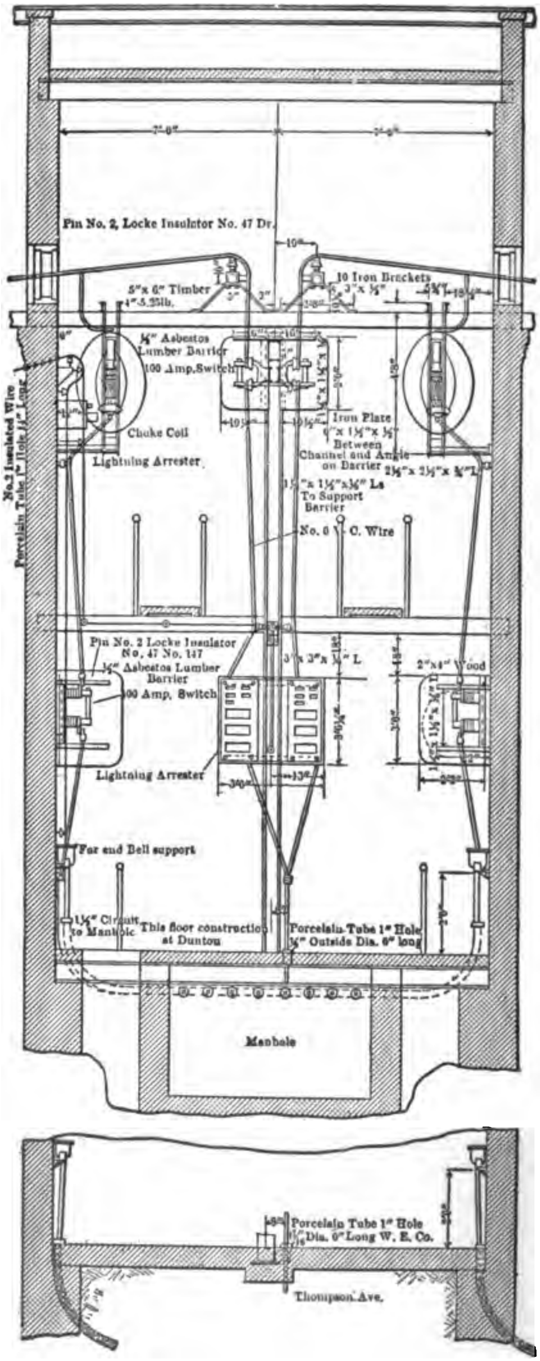


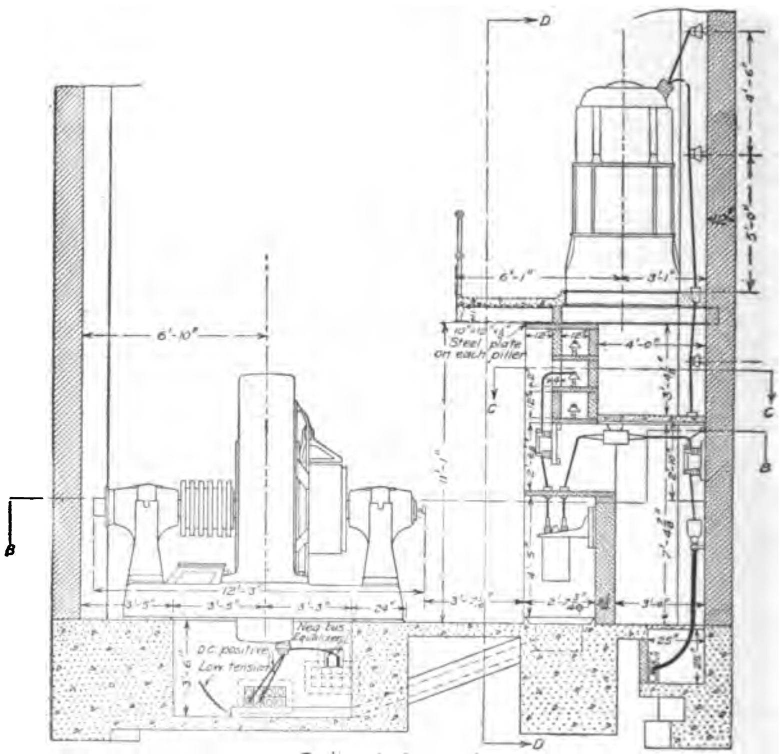
FIG. 268.—Cross Section of Lightning Arrester House, Long Island Railroad.

Rate.	Time	Rating.
700 amp.	8 hr.	5600 amp-hr.
1000 "	5 "	5000 " "
1500 "	3 "	4500 " "
3200 "	1 "	3200 " "

The normal rating of the battery is on the basis of one hour, for which time it can be discharged at the rate of 3200 amp. In case of necessity, however, the battery can discharge at the rate of 6400 amp. for 20 minutes. For instantaneous fluctuations it can discharge up to a momentary maximum rate of 9600 amp. For charging and discharging of the battery, and hence its proper maintenance as a regulator to maintain a comparatively steady load on the converters, there are used two direct connected, motor-driven, separately excited boosters. Each consists of one three-phase induction motor for 25-cycles at 400 volts rated at 235 hp. and of a booster-generator rated to deliver 1200 amp. at 135 volts. The overload capacity of the latter is 1600 amp. for one hour and 3200 for two minutes. The transformer equipment which supplies the motor consists of three 200-kv-amp. air-blast transformers. The field of the booster is excited by a small booster exciter-generator driven by a 3-phase, 400-volt, 25-cycle induction motor. The strength of the field and the polarity of the booster-exciter field-coils are regulated by a carbon regulator manufactured by the Electric Storage Battery Company. By the aid of this regulator the polarity and field strength of the exciter change instantaneously with the fluctuations in the main circuit, which in turn produces changes in the excitation of the booster. This latter regulates charging and discharging of the battery. In this way the fluctuations of the load on the converters may be adjusted within a wide range (from 5 per cent. to 50 per cent.).

Wherever an underground feeder changes to an overhead line, lightning arrester houses are installed. Fig. 264 shows the location of two of these houses, one at Dutch Kills Street, and the other at Dunton, and three others on the line going to Hammel substation. In Fig. 268 the cross section of the Dutch Kills lightning arrester house is shown. It is a brick structure and contains room for eight outgoing overhead circuits which leave the house four on a side. The arrester house

is 33 1.5 feet in length, 17.5 feet wide and 30.5 feet high inside. The steel beams supporting the apparatus extend to the outside of the building, forming a series of racks for the support of transmission cables which are dead-ended upon them. The arresters are all provided with knife switches. Resistance coils are built in, in series with each main circuit and another knife



Section A-A. Incoming line.

FIG. 269.—Cross Section De Kalb Ave. Substation. (Coney Island and Brooklyn R. R. Co.)

switch between the coil and the cable bell. The disposition of the material is such as to economize space and at the same time make each circuit capable of ready access without incurring risk from other apparatus. The incoming cables are carried through the floors by means of ducts reaching to the last manhole in the conduit line, and are arranged along the wall running through the switches and through the reactance

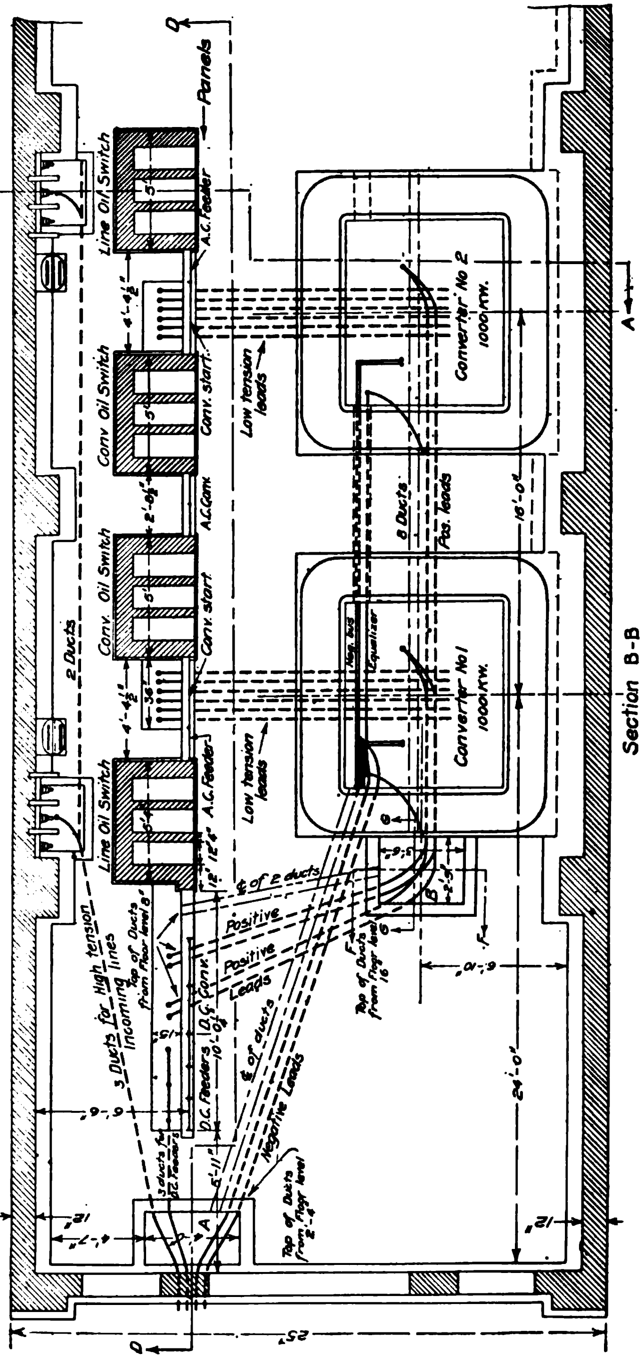


FIG. 270.—Plan of De Kalb Ave. Substation. (Coney Island and Brooklyn R. R. Co.)

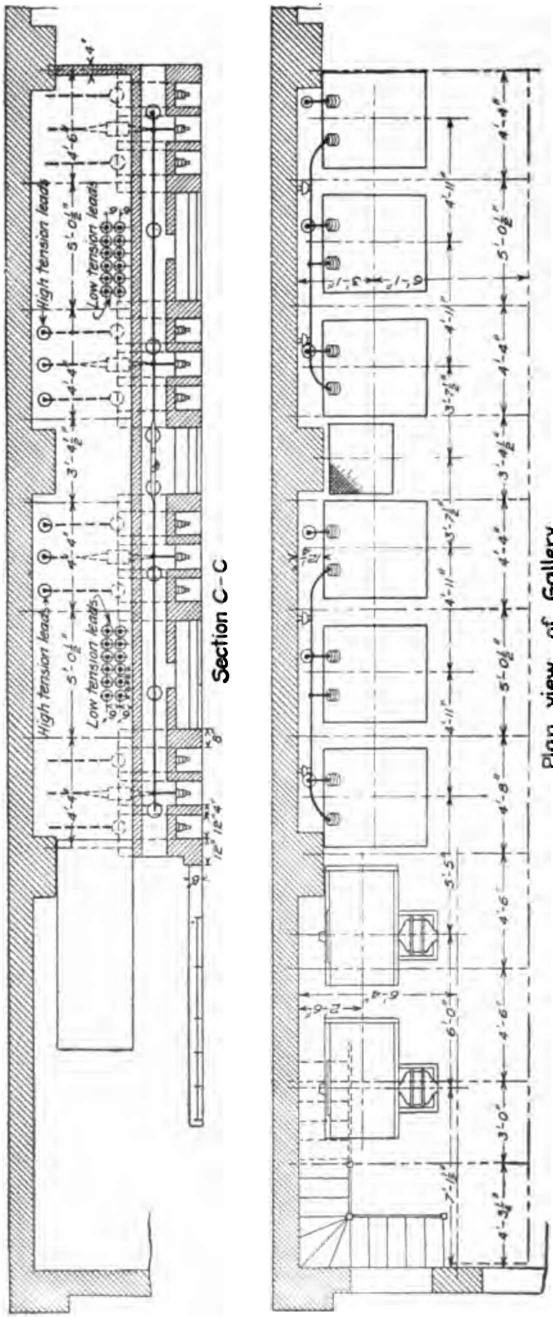


FIG. 271.—Plan of Bus Structure and of Gallery Floor of De Kalb Ave. Substation.

coils to the various outlets. The arresters are mounted on either side of the steel framework in the center of the building and the ground connections all run to a single ground lead consisting of a 5.5-sq. ft. copper plate buried in the ground between layers of crushed coke. The outlets and arresters are the same as in the station previously described.

CONEY ISLAND AND BROOKLYN RAILROAD COMPANY SUBSTATION

Figs. 269, 270, 271, 272 and 273 show the arrangements designed by the author for the substation in De Kalb Avenue.

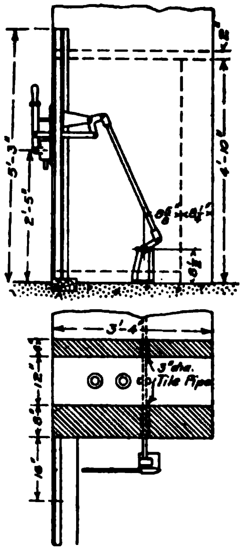


FIG. 272.—Detail of Oil Switch Pipe Mechanism.

The building is typical for city service where real estate is expensive. It is built on a lot 25 ft. wide and is at present equipped with two 1000-kw. converters. If necessary, the rear of the building can be extended so as to accommodate two additional units. The narrowness of the building necessitates a special gallery arrangement for the apparatus. Four three-pole oil switches (2 for incoming line and 2 for the machines) are set up in separate cell structures, the end walls of which are continued upward so as to carry the gallery with the air chamber and busbar compartments. The inner partitions of

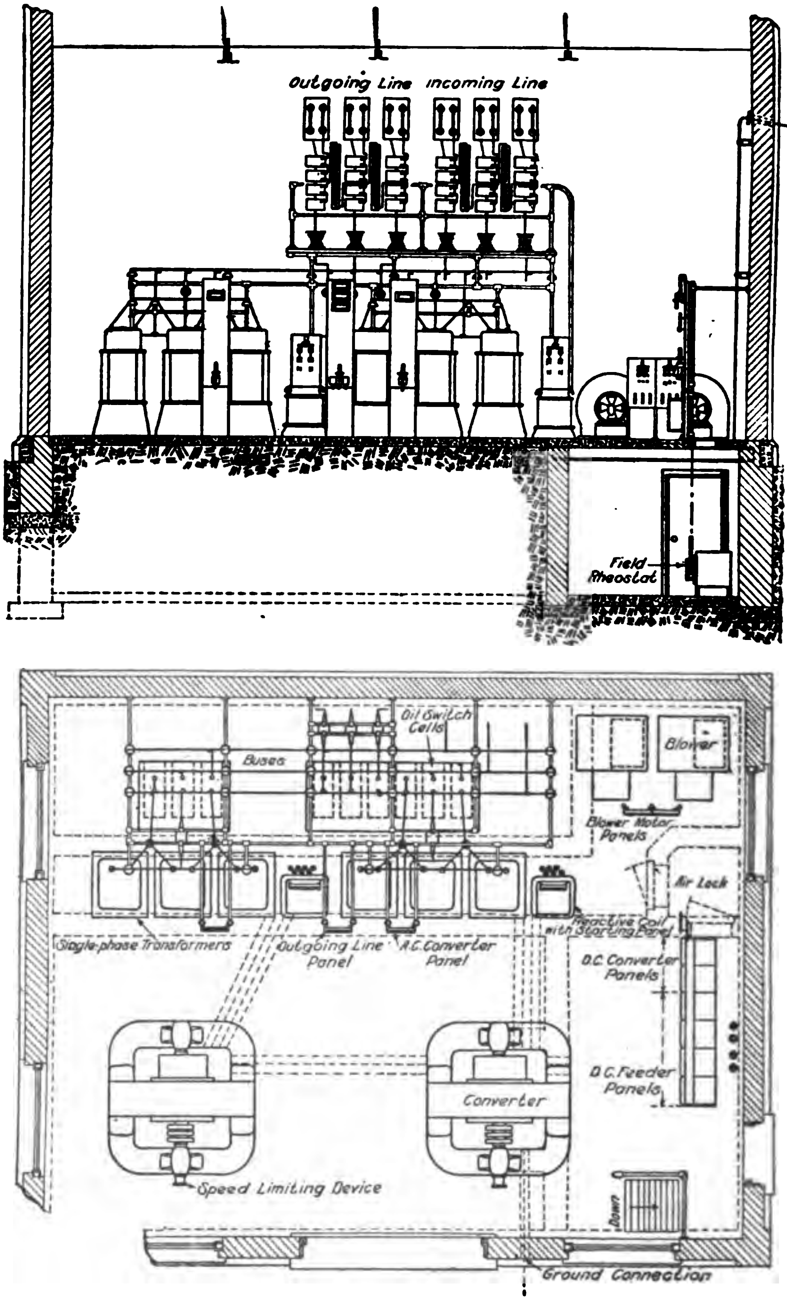


Fig. 274.—Plan and Elevation of a Standard Converter Substation for 13,200 Volts, with 300-kw. Machines and Single-Phase Air-Blast Transformer.

the structures also run up to the gallery, but serve only as barriers for the separation of the busbar connections. The high-tension three-conductor cables are led in ducts to the wall back of the oil switches where they diverge and are joined to the disconnecting switches. From here they run on to the

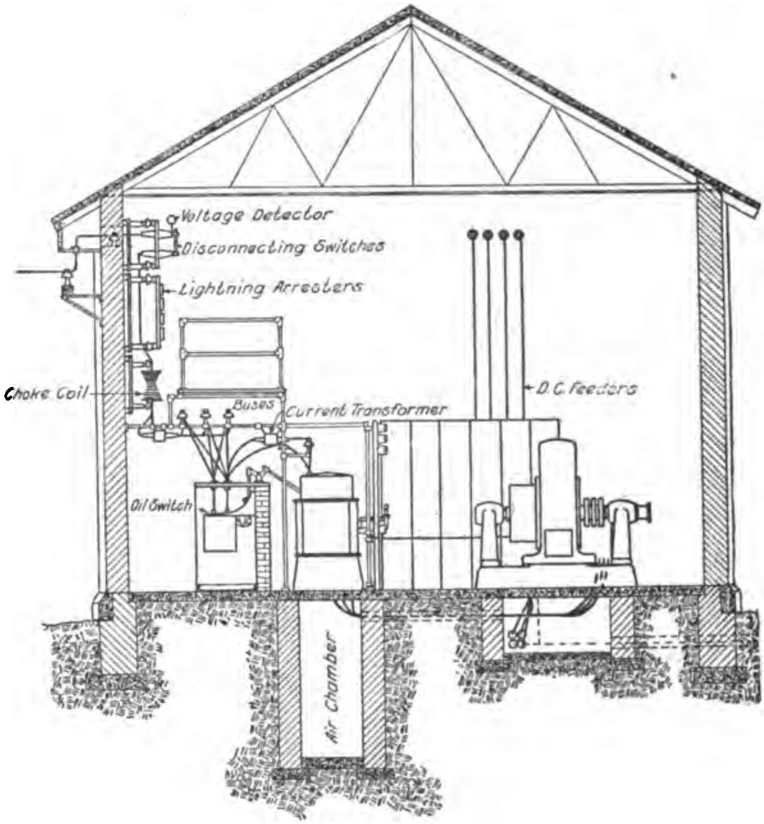


FIG. 275.--Cross Section of Station Shown in Fig. 274.

ceiling of the air-chamber to the oil switches. All oil switches are type K4, (G. E. Co.), three single-pole making one triple-pole. They are operated by means of a pipe mechanism and shafting. Each oil switch set has its own operating board placed at its side and the operating shaft passes through openings in the cell walls. From the oil switches the cables are led through disconnecting switches to the 11,000-volt buses and

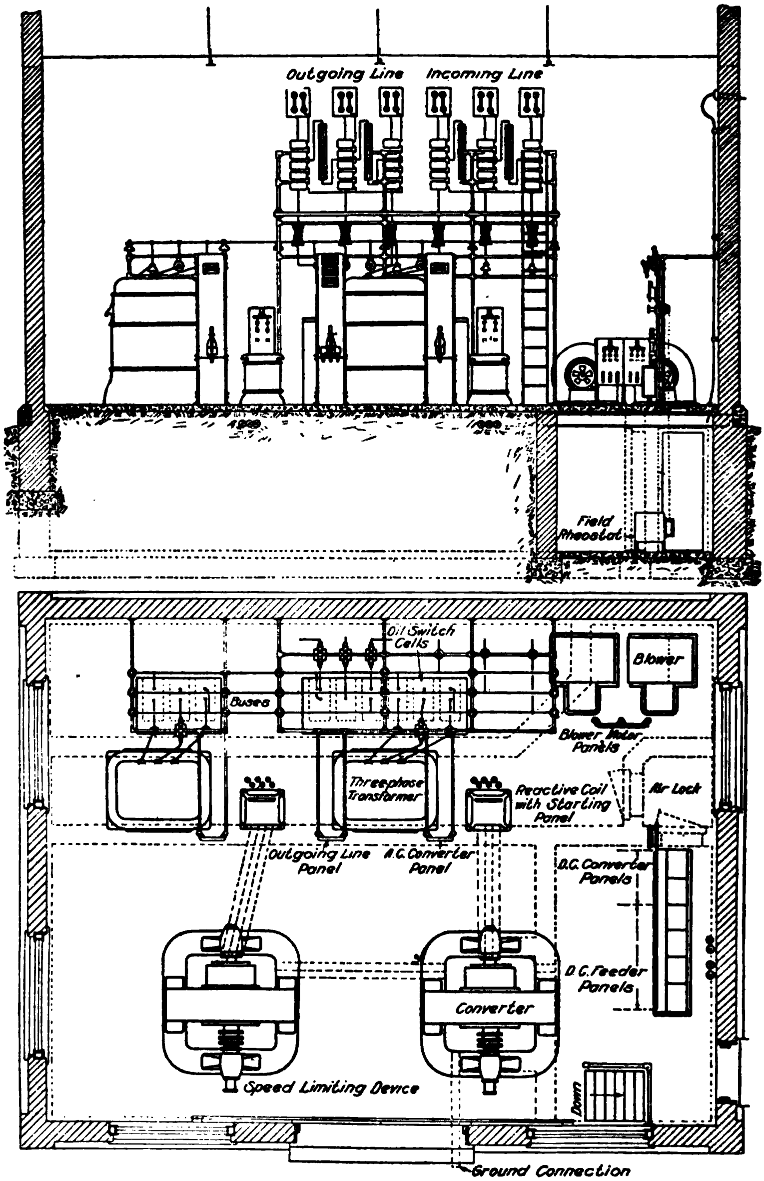


FIG. 276.—Plan and Elevation of a Standard Converter Substation for 13,200 Volts, with 300 kw. Machines and Three-Phase Air-Blast Transformer.

from here they pass through another series of disconnecting and oil switches up to the air chamber and the transformers on the gallery. The transformers are air-cooled, 11,000 to 430-volt and 375-kw. rating each. Their high-tension side is star connected.

The low-tension cables lead from the transformers to the starting panels which are located opposite each machine,

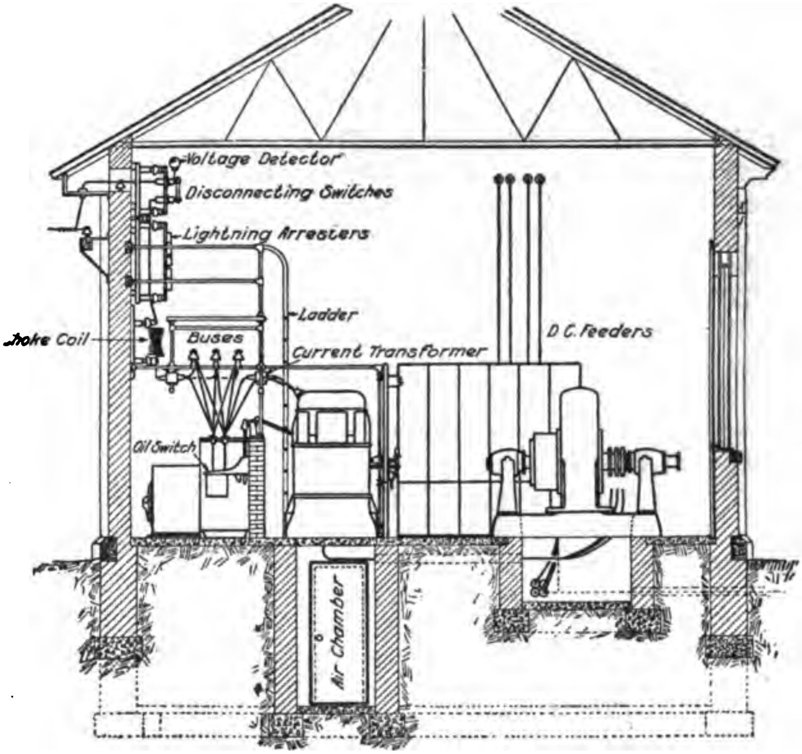


FIG. 277.—Cross Section of Station Shown in Fig. 276.

whence they run in ducts through the machine foundations to the converters. The positive cables, and the negative and equalizer buses are contained in ducts and openings in the converter foundations, the former running from the manhole B to their d.c. panels while the negative cables lead from the same machine side to the main manhole A, to which the outgoing d.c. feeders are also led. On the gallery there are, besides the transformers, two blower sets, each driven by a 4-hp. induction

motor at 350 volts and 750 rev. per min. Note the concrete blocks under the individual cells which serve as foundations for the walls supporting the gallery. All a.c. panels are set up between the oil-switch cells. The d.c. board on the other hand is in line with the cells at the end of the row. The busbars are sectionalized and the bus compartment has rather large openings at the section points for operating the disconnecting switches.

Since all machines and apparatus are made in standard forms, it is often found convenient to standardize their arrangement in the station. This makes each station a concrete unit which may be dealt with as such. The equipment for a traction system substation might thus be given by a specification formula such, for instance, as follows:

One M-kw. type Q. converter 25-cycle.

Three $\frac{M}{3}$-kw. type R. transformers.

One high-tension panel board type S.

One low-tension panel board type T.

One lightning arrester 3-phase type W.

Oil switches and cables.

Make up in brick compartments.

Take one station for each M miles of track.

In the following plates, 274 to 281, there are shown a number of arrangements for traction system substations for various high-tension values and kilowatt ratings of the machines, and for different types of transformers and oil switches. These plans were prepared by the General Electric Company, and are intended to give the normal arrangements for the particular kind of service for which they are designed. It is assumed in all cases that there is sufficient floor space available.

Figs. 274 and 275 installed at present:

Two 300-kw. 3-phase synchronous converters, 25-cycle.

Six 110-kw. single-phase, air-blast transformers, $\frac{13200}{2300}$ volts, Δ connected.

Two blower sets (motor operated).

Two reactance coils with starting panels.

Three alternating-current high-tension panels: 2 machines, 1 outgoing feeder.

Two alternating-current low-tension panels: 2 induction motors for blowers.

Six direct-current low-tension: 2 machines, 4 feeders.

Two lightning arresters: 3-phase for Δ circuit, multigap, multiplex.

Six reactance coils.

Nine hand-operated oil switches, K2 or K4 type, S. P. S. T. in cells.

High-tension buses and insulator supports.

Brickwork for cells, air chamber, machine and basement foundation.

Tile ducts for low-tension a.c., for equalizer, negative and ground connection cables.

Wall outlets for overhead high and low-tension lines.

Gallery for lightning arresters.

Frame support for high-tension buses and panels.

Cables.

Space is provided for another oil switch set for a second outgoing feeder or for eventual use of oil switches for the incoming feeder. The building can be extended to the left without interrupting the service.

Figs. 276 and 277. At present installed.

Two 3-phase, 25-cycle, 300-kw. synchronous converters.

Two 330 kw., 3-phase, air-blast transformers $\frac{13200}{370}$ 13,200 to 370 Δ connected volts.

Two blower sets (motor operated).

Two reactance coils with starting panel.

Three alternating-current high-tension panels: 2 machines, 1 outgoing feeder.

Two alternating-current low-tension panels: 2 induction motors for blowers.

Six direct-current panels: 2 machines, 4 feeders.

Two lightning arresters: 3-phase for Δ circuits, multigap, multiplex.

Six reactance coils.

Nine hand-operated oil switches, K2 and K4 type S. P. S. T. in cells.

High-tension buses and insulator supports.

Brickwork for cells, air chambers, machine foundations and basement.

Tile ducts for low-tension alternating current, for equalizer, negative and ground connection cables.

Wall outlets for overhead high-tension and low-tension lines.

Gallery for lightning arresters.

Frame support for high-tension buses and panels.

Cables.

Space is provided for another oil switch set for a second outgoing feeder or for eventual use of oil switches for the incoming feeder. The building can be extended to the left without interruption of service.

For a similar station with oil-cooled transformers the equipment is as follows:

Two 3-phase, 25-cycle, 300 kw. synchronous converters.

Six single-phase, 110-kw. oil-cooled transformers, $\frac{13200}{2300}$ volts, Δ connected.

Two reactance coils with starting panel.

Three alternating-current high-tension panels: 2 machines, 1 feeder.

Six direct-current low-tension panels: 2 machines, 4 feeders.

Lightning arresters: 3-phase for Δ circuit, multigap, multiplex.

Six reactance coils.

Nine hand-operated oil switches, K2 or K4 type, S. P. S. T. in cells.

High-tension buses and insulator supports.

Brickwork for cells and machine foundations.

Tile ducts for low-tension direct-current equalizer, negative and ground connection cables.

Wall outlets for overhead high-tension and low-tension lines.

Gallery for lightning arresters.

Frame support for high-tension buses and panels.

Cables.

Figs. 278 and 279.

Three 6-phase, 25-cycle 500 kw. synchronous converters.

Nine single-phase, 185-kw. air-blast transformers, $\frac{33000}{2300}$ volts, Δ connected.

Two blower sets (motor operated).

Three reactance coils with starting panels.

Seven alternating-current high-tension panels: 3 machines, 2 outgoing and 2 incoming feeders.

Two alternating-current low-tension panels: 2 induction motors for blowers.

Nine direct-current low-tension panels: 3 machines, 6 feeders.

Four lightning arresters: 3-phase for Δ circuits, multigap, multiplex.

Twelve reactance coils.

Twenty-one hand-operated oil switches, K6 type, S. P. S. T. in cells.

High-tension buses and insulator supports.

Brickwork for cells, air chambers, machine foundations and basement.

Tile ducts for low-tension a.c. cables.

Wall outlets for high-tension and low-tension lines.

Railing and frame support for insulators and high-tension buses and panels.

Cables.

Note the separate compartments for the lightning arresters.

The building may be extended to the left with little trouble.

Figs. 280 and 281.

	Present Equipment	Room for Future Addition
Six-phase, 25-cycle, 1000 kw. converters..	3	1
Single-phase 375 kw. air-blast transformers, $\frac{13200}{2300}$ volts, Δ connected........	9	3
Blower sets (motor operated)..........	2	1
Reactance coils with starting panels....	3	1
Alternating-current high-tension panels, 3 machines, 4 feeders..................	7 & 1 blank for	1
Alternating-current low-tension panels, 2 induction motors for blowers..........	2	1
Direct-current low-tension panels, 3 machines, 12 feeders....................	15 & 1 blank for	1
Motor-operated H3 oil switches in cells each 3-S. P. S. T.....................	7	1

High-tension bus and insulator supports.

Static dischargers for the underground transmission line.

Brickwork for cells, compartments, air chambers, machine foundations and basement.

Tile ducts for high-tension and low-tension feeders.

Frame supports for switchboard and insulators.

Cables.

Storage battery for motors on H3 switch (with panels).

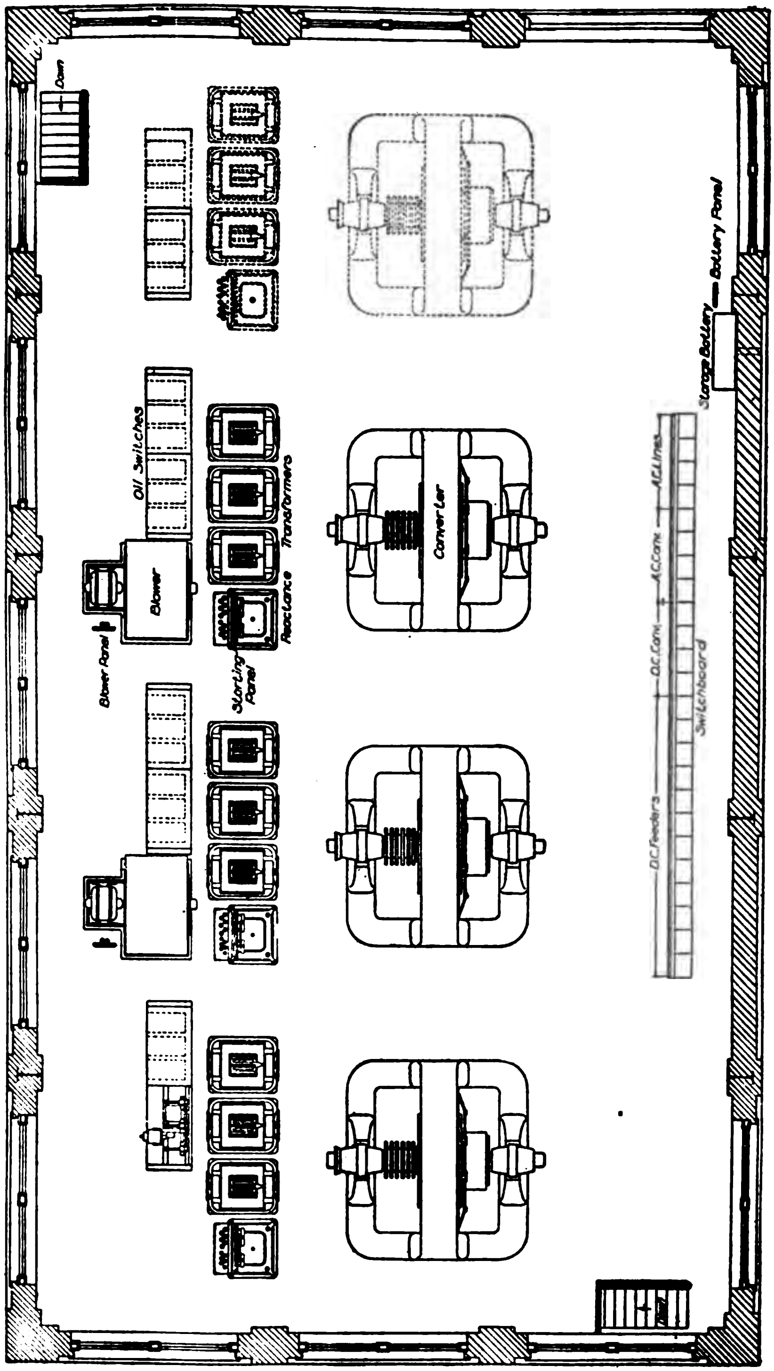


FIG. 280.—Plan of a Standard Converter Substation for 13,200 Volts, with 1000-kw. Machines and Single-Phase Air-Blast Transformers.

Space and foundations are provided for installing a fourth converter with accessories. The building may be extended in either direction.

PORTABLE SUBSTATIONS

The uses to which portable substations are put were stated in the previous chapter. Under the description of the Long

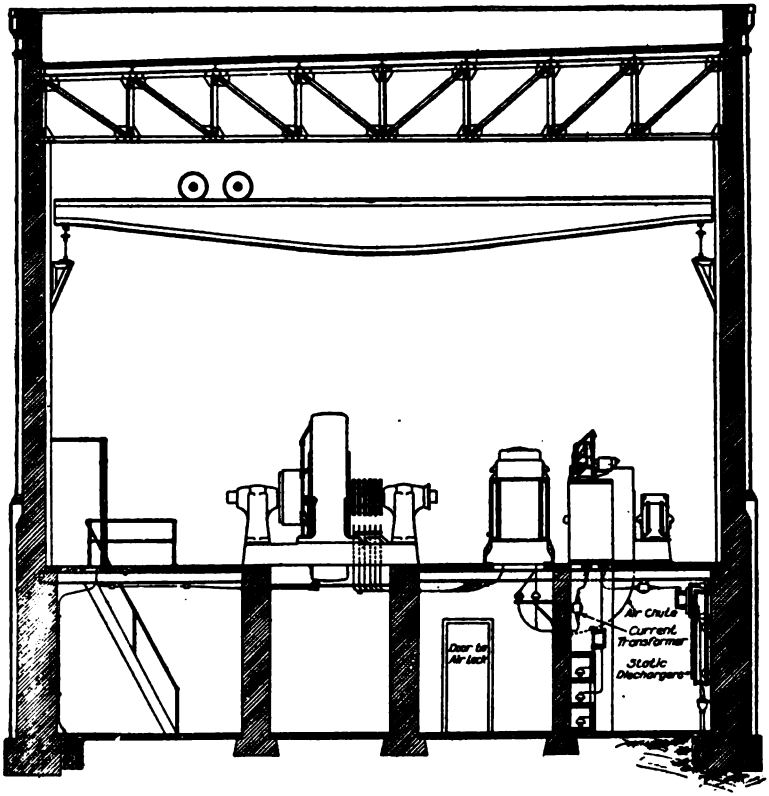


FIG. 281.—Cross Section of Station Shown in Fig. 280.

Island R. R. system two such stations were mentioned which are used during the racing season at Belmont Park and at the Metropolitan Race Track. Each of these stations is equipped with a 1000-kw. converter which is identical with those used in the regular stations, and with three 375-kw. air-blast transformers with the accompanying ventilator equipment and auxiliary apparatus. Fig. 282 shows the arrangement of this

apparatus in the car. The floor of the car is of very strong steel construction while the sides and roof are made as light as possible. The converter is set up in the end of the car, and this part can easily be taken apart so that the machine may be dismounted or removed if necessary. At the other end there are the three symmetrically arranged transformers. They are easily removable, and can be lifted through the roof of the car by the traveling cranes of any of the substations. They are mounted on a raised chamber which is supplied with air from the blower. The latter delivers 4500 cubic feet of air per minute at a pressure of 1 oz. It is driven by a three-phase 3-hp. 400-volt induction motor which is supplied from the a.c. board from the low-tension side of the transformers.

The high-tension lines come into the car through three inlets on the high-tension side. They are first led to an oil switch (type C. Westinghouse, 600 amp.) enclosed in a yellow pressed brick cell, whence they run along the roof of the car to the delta connection on the high-tension side of the transformers. The space between the oil-switch cells and the transformers is accessible through doors in the side of the car. There are three switchboards in the car. The first is provided with several switches making possible four combinations of voltage from the low-tension side of the transformers, and the second and third are the a.c and the d.c. boards. The converter is started by an induction motor. The induction motor section also contains the switchboards and is accessible through doors. The d.c. feeders leave the car on one side near the d.c. side of the machine. When in service these cars are housed in specially constructed sheds where they are connected up with the high-tension line. The necessary lightning arresters are therefore installed in the towers of these sheds, the arrangement being similar to that described above for lightning arrester houses.

Direct current for operating the oil-switch solenoids is drawn directly from the third rail, and the solenoids must therefore be wound for 500 volts. Note the method of mounting the shunt transformers on either side of the oil switch and of the series transformer on the roof of the car. All cables in the car are laid under the machines and transformers. The control and operation of the machines are exactly the same as in all of the other substations of the system.

In order to secure a rigid base for the machines when in service, the car is lifted off its trucks and springs. The car alone weighs 49,000 lb., and the weight of the equipment is 142,400 lb.

Figs. 283 and 284 show a portable substation equipped with General Electric machines and apparatus, used by the Cincinnati and Columbus Traction Company. The converter is a 400-kw. 3-phase, 25-cycle machine and delivers a 600-volt direct current. A three-phase air-blast transformer $\frac{16500}{3300}$-volt-370-volt, delivers the necessary low-tension current for the converter. The latter is started on the a.c. side through two double-throw switches, which at starting connect the machine to a low voltage and when running to a 370-volt circuit. The machine and transformers are placed in opposite ends of the car in order to balance the weight as much as possible. A number of wooden blocks are fastened to the floor of the car and hold the cast iron frame of the machine in place. The high-tension lines are brought in through inlets protected against rain, etc., and are led to the three single-pole oil switches which are mounted on wooden supports on one side of the car. These supports also carry the operating mechanism, which is actuated from the switchboard through a linkage system. The starting and control panels are placed side by side while all instruments for both the d.c. and a.c. sides are mounted on individual bases directly on the walls of the car. The negative machine terminals are directly connected with the steel work of the car. A disconnecting switch is provided for connecting the negative side with the equalizer bus in case the car is used as a reserve station or is run in parallel with a stationary substation. The positive cables run from the circuit breaker through the side of the car to a terminal stud on the outside to facilitate connection to the third rail. Lightning arresters are provided near the inlets of the high-tension cables. There are a number of openings in the roof over the transformers so that these may be accessible for repairs or removal. In the middle of the car there are two doors and besides this there are a number of windows in the sides for illumination.

The approximate dimensions for cars with machines of different kilowatt ratings are given in the following table. The

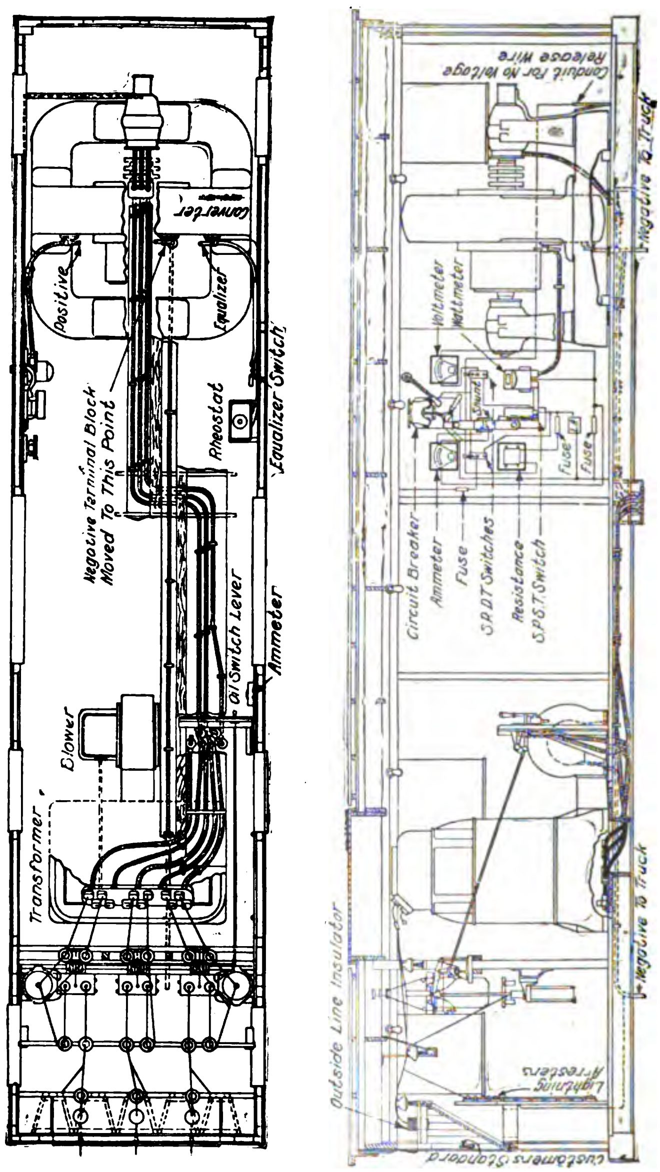


FIG. 283.—Plan and Elevation of a Portable Substation with a 400-kw. Converter and a Three-Phase, 25-Cycle, $\frac{14400}{1900}$-870-Volts Air-Blast Transformer.

first three are those recommended by the General Electric Company, and the fourth is that used by the Long Island Railroad Company, where Westinghouse machines are employed:

Rating of Converter.	Length.		Width.		Height.	
kw.	ft.	in.	ft.	in.	ft.	in.
200	30	00	7	6	7	6
300	34	6	8	10	8	6
400	41	00	9	00	8	6
1000	36	8	9	10	9	0

TRANSFORMER STATIONS

A distribution system for single-phase railway service with single-phase transmission is indicated in Fig. 285.

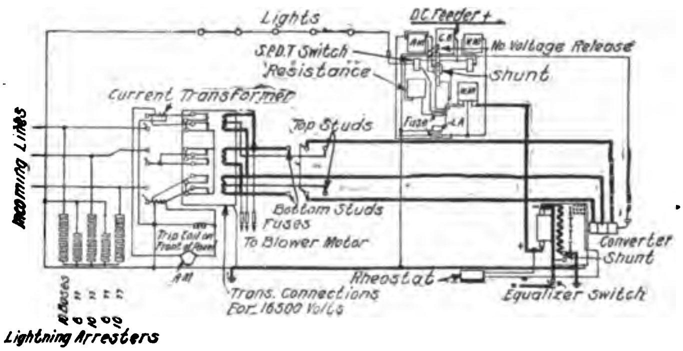


Fig. 284.—Wiring Diagram of a Portable Substation.

The connections between the intermediate and terminal substations are also shown. In the intermediate station the incoming and outgoing lines are connected to 22,000-volt transfer buses, which supply the auxiliary buses in the station. Both terminals on the high-tension side of the transformers are connected to the auxiliary bus, and one terminal on the low-tension side is grounded while the other is connected to the 2200-volt bus. The trolley wire is sectionalized in front of both substations and the immediate section is fed by both of the stations. The low-tension feeders have single-pole automatic oil switches, and the high-tension have double-pole switches. With the exception of the outgoing feeders the end station is identical with the intermediate stations. All in-

coming and outgoing feeders are protected by lightning arresters.

Fig. 286 shows the distribution for a single-phase railway system, with three-phase transmission, double track. The high-tension side is analogous to that shown in Fig. 285 with the exception that there are banks of two transformers connected three-phase-two-phase to supply the low-tension buses instead of one, as before. The two phases supply different sections of the two trolley lines, a given phase always feeding

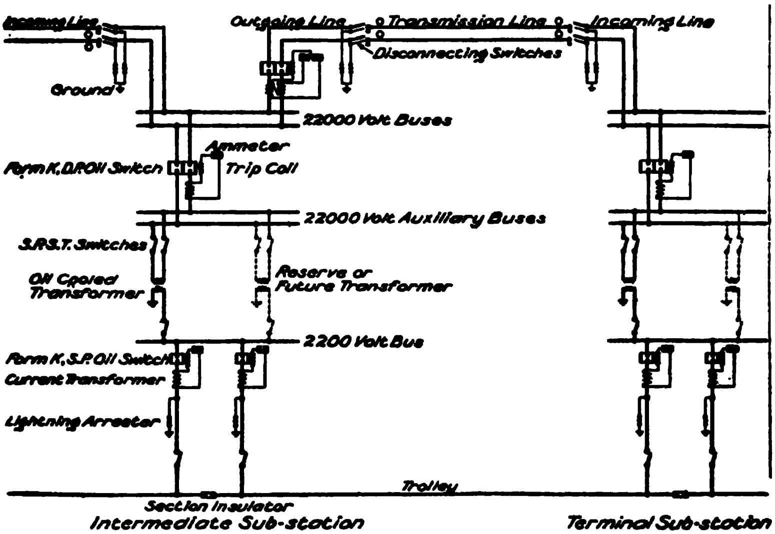


Fig. 285.—Distribution System for Single-Phase Railway, Single-Phase Transmission.

the same trolley. If only one trolley is used its sections are supplied alternately by both phases.

ROCHESTER DIVISION OF THE ERIE RAILROAD

An extract of Mr. W. N. Smith's paper published in *Street Railway Journal.** This line was the first in this country to operate electric cars on a single-phase system, over the tracks of an operating steam railroad. Further, it was the first to use 11,000 volts' working pressure on a trolley, and the first instance of a single-phase traction system, receiving power

* "Single Phase Electric Motive Power on the Rochester Division of the Erie Railroad," by W. N. Smith. *Street Railway Journal*, Oct. 12, 1907.

from a 60,000-volt transmission line. The energy is supplied from the plant of the Ontario Power Company at Niagara Falls, at 60,000 volts' pressure, which is stepped down at the Avon substation to 11,000 volts' working pressure. Figs. 287, 288 and 289 are the plans and cross sections and wiring diagram of this substation.

The building is of brick resting on solid concrete foundations, the roof and floors being of reinforced concrete. The

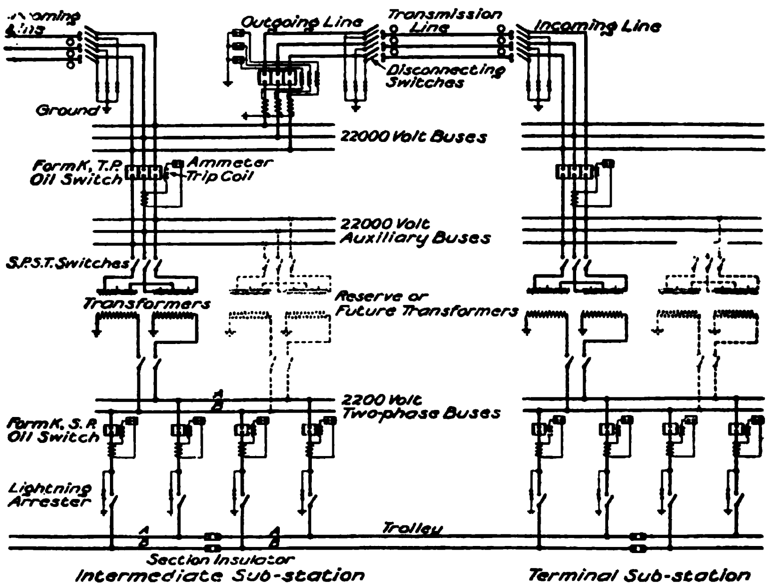


FIG. 286.—Distribution System for Single-Phase Railway, Three-Phase Transmission, Double Track.

floors are supported upon steel beams but the roof beams are of reinforced concrete like the slabs which they support. The building is absolutely fireproof, the doors and windows being of kalomein construction and fitted with wire glass. It is 39 ft. 8 in. by 44 ft. 00 in. outside and 29 ft. 10 in. high from the top of the foundations to the top of the parapet. In the basement are located one of the transformer oil tanks and the oil pump. The main floor is divided into three rooms, the main transformer room being 43 ft. by 17 ft. and extending the full height of the structure to allow room for the high-tension bus-

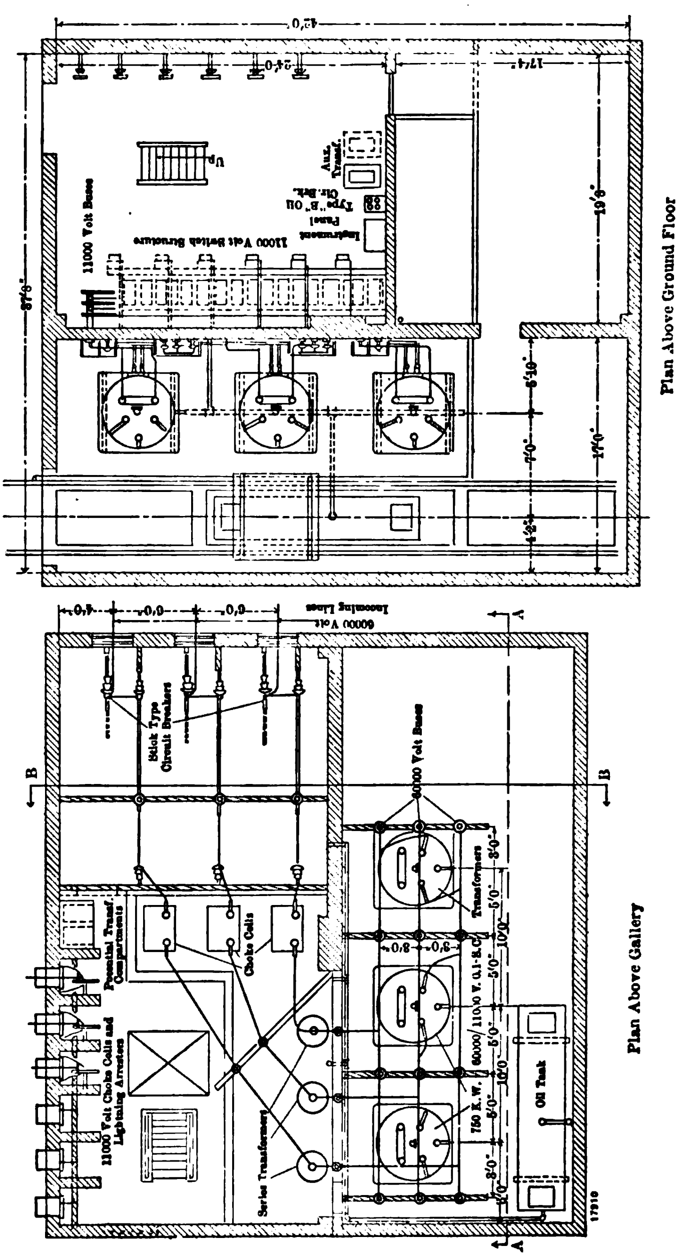
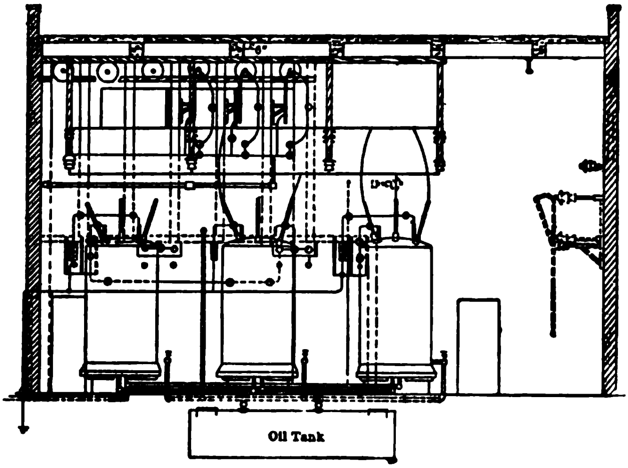
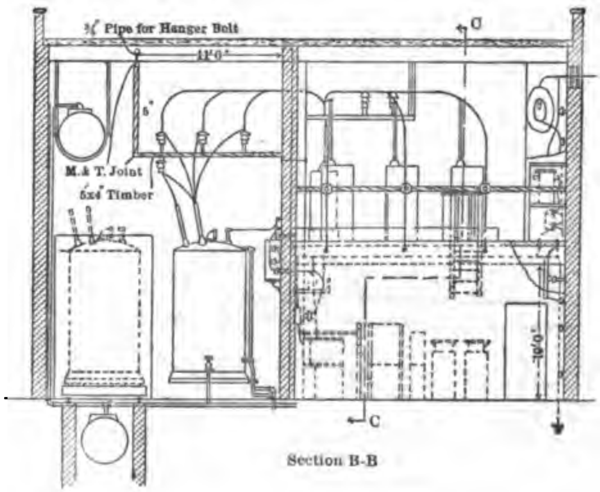


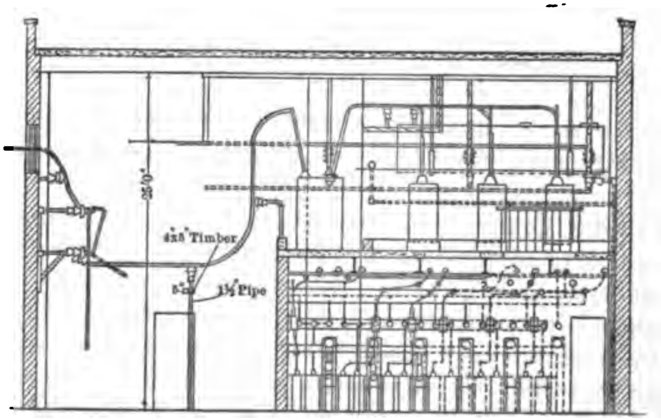
FIG. 287.—Plan of Avon Substation.



Section A-A



Section B-B



Section C-C

FIG. 288.—Plan and Elevation of Avon Substation.

bars which are carried over the transformers. The remaining space on the main floor is divided into a high-tension room (through which the 60,000-volt wires enter and which is the location of the high-tension circuit breakers, 16 ft. 8 in. by 19 ft. 8 in.) and the operating room which is 19 ft. 8 in. by 24 ft. 00 in. where all the 11,000-volt switching apparatus and the measuring instruments are located. Directly over the operating chamber is a mezzanine floor, reached by an iron stair-

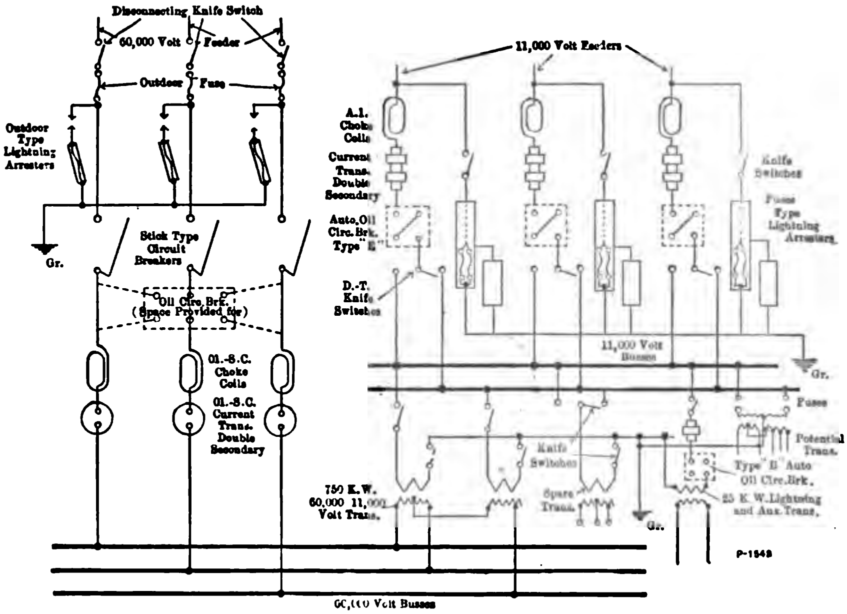


FIG. 289.—Diagram of Connections of the Avon Substation.

case, in which are located 11,000-volt lightning arresters, the 60,000-volt reactance coils and the 60,000-volt series transformers.

The transmission line terminates at the lightning arrester yard in the rear of the substation. The arrangement of the 60,000-volt lightning arrester consists of three horn gaps arranged one behind the other on each of the three conductors, the first gap being 4.75 in. across, the second 5 in. and the third 6 in. A concrete column is in series with the first gap, an electrolytic arrester in series with the second and a 5-ft. fuse

of No. 18 copper wire in series with the third, that is between horn and ground. Both horns of each gap are 1.5 in. round iron. Between the line and the first arrester there is a hook-type knife switch, and between the last arrester and the lead going into the substation there is a No. 18 copper wire fuse in each conductor, placed horizontally. These fuses are enclosed in wooden tubes about 5 ft. long, wrapped with torpedo twine. The entire arrangement of lightning arrester gaps, fuses and switches is mounted upon 18 chestnut poles and a suitable elevated platform railed off and fitted with a gate to keep out trespassers.

The three high-tension conductors enter the substation through glass disks held in 36-in. tile set in the upper portion of the rear wall of the substation. Within the substation the wires first pass to three 60,000-volt stick-type circuit breakers mounted directly inside of the rear wall. Thence they run over bare copper conductors to the three oil-insulated reactance coils situated on the mezzanine floor, thence through three oil-insulated series transformers, also on the mezzanine floor, and finally through a wide opening in the division wall to the 60,000-volt busbar in the transformer room. The busbars are mounted upon porcelain insulators on wooden cross arms at a convenient height over the transformers.

The transformers are of the Westinghouse oil-insulated, water-cooled type, each of 750 kw. For the present installation two only are used, the third and middle one being the spare. The high-tension connections are such that in case of one transformer failing while in service, its connection can quickly be taken off of the busbars and put on the spare transformer. The transformer windings are fitted with taps enabling the three-phase-two-phase "Scott connection" to be used. The low-tension windings can be so connected that 11,000 or 22,000 volts can be obtained, the latter to be used in case another substation for a 40 or 50-mile extension is added. The low-tension windings also have six taps enabling small variations in the secondary voltage. One end of each low-tension winding is directly grounded to the boiler iron case which in turn is directly connected to the track return circuit by means of a No. 4 copper stranded cable. The transformer cases are made of boiler iron and are set on a square cast iron base

which is mounted on three pairs of wheels running upon an iron sub-base set in the concrete floor of the room. A track runs lengthwise across the room directly in front of the transformers. A transfer truck runs upon this, and on the top of the truck there is another set of small wheels which line up with those on which the transformer cases are set.

Two cylindrical boiler-iron oil tanks are provided. One is located in the basement directly under the transformer room so that the oil from the transformer can readily be drained into it and the other is suspended from the concrete roof beams at the top of the transformer room, close to the side wall of the building. This is intended to act as a reservoir for distributing oil back into the transformers. The oil is pumped from the lower to the upper tank by means of a steam pump supplied from the boiler room in the adjacent division roundhouse where steam is always available.

The water circulation is by gravity, the supply coming from the railroad company's water tank system. There are three separate water-cooled coils in each transformer case, each one controlled by its own valve.

The low-tension busbars run along the division wall of the operating room and directly beneath them are three type E Westinghouse automatic oil switches, one on each of the two trolley feeders, the third or middle one being the spare. One pole of each of the three oil switches is connected to the center pole of a double-throw hook type switch by means of which it is thrown upon either busbar. The other pole of the oil switch runs directly to the feeder. The outgoing lead from the middle or spare oil switch can instantly be thrown upon either one of the feeders should the oil switch controlling that feeder be temporarily disabled. The outgoing 11,000-volt feeders run up to the mezzanine floor directly over the operating room where they emerge from the building through perforated glass disks set in 18-in. round tiles. Before emerging there are tapped to them two Westinghouse low-equivalent lightning arresters set in brick compartments and reinforced by two electrolytic lightning arresters of the 11,000-volt type.

A set of call bells is provided so that when the oil switch is open a bell is rung in the car inspection shop adjoining. Also, if the temperature of any transformer runs above normal

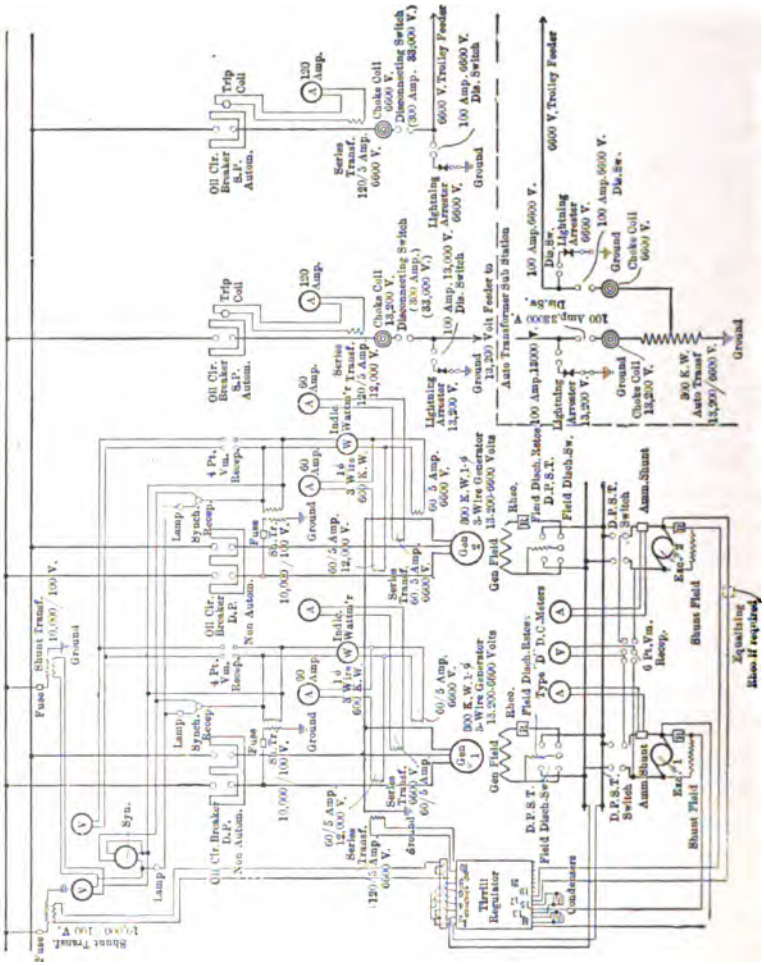


FIG. 290.—Wiring Diagram of Powerhouse and Substation of the Windsor, Essex and Lake Shore Rapid Railway.

a bell circuit connected to the thermometers in the top of the transformer tank is similarly made to operate. The station itself does not require the continuous presence of an attendant. The working force is so organized that the car repair men are always available for manipulating the substation oil switches.

On the mezzanine floor there is room for an oil switch eventually to be installed for the 60,000-volt incoming line. There is also space for a fourth transformer and for a number of type E oil switches.

WINDSOR, ESSEX AND LAKE SHORE RAPID RAILWAY

In Fig. 290 there are shown the wiring diagrams of the central and substations of the above system which employs 6600 volts' pressure in the overhead trolley.

The central station is equipped with two generators of 500 kw. 25-cycle, single-phase, three-wire, fly-wheel type. The windings of these generators are such that from the terminals there may be obtained current at 13,200 volts' pressure and also at 6600 volts. The two windings may be used in series for obtaining these two voltages or may be connected in parallel for obtaining the full rating of the machine at 6600 volts. One of the three terminals of each machine is grounded. The exciting current for each generator is furnished by a 30-kw., 125-volt belted generator, the field current of which is varied by a Tirrill regulator to obtain smooth voltage regulation for the units.

Energy is supplied to two buses in the central, one at 13,200 volts which feeds the substation, and one at 6600 volts which feeds directly a section of the trolley line. The 13,200-volt single-wire transmission line feeds a 300-kw. auto-transformer in the substation, which in turn supplies the other section of the trolley wire at 6600 volts. The station is equipped with the necessary oil switches for the supply to the buses and the two outgoing feeders. The substation contains only the auto-transformer and the necessary lightning arresters and reactance coils. The switchboard for regulating and controlling the output of the generating station comprises five panels, one exciter, two machines, one 6600-volt feeder and one 13,200-volt feeder. Enclosed in concrete cells back of the switchboard are two machine and three feeder switches. These are distant controlled oil switches, type E. The high-tension wiring

within the station is composed of lead covered cables enclosed in fiber conduits. The trolley wire is divided into two sections, the 18-mile section fed from the power house and the 12-mile section from the substation.

THE SPOKANE INLAND RAILROAD COMPANY *

The Inland Empire System of this railroad operates with energy purchased from the Washington Water Power Company. The output of this company's plant is delivered at 60 cycles, three-phase and 4000 volts. In the purchase of the energy the charges are based upon the maximum demand during each month and for this reason it became very desirable to employ some means to flatten the railway load curve as well as it was necessary on account of the motor characteristics to change the frequency from 60 to 25 cycles before feeding the energy to the railway transmission line. The problem was solved by combining phase-changing induction motor-generator sets on the same shafts with direct-current railway machines which utilize a large storage battery as a fly-wheel.

The station equipment consists of four main units each made up of three machines. In each set a 1000-hp. induction motor takes three-phase 60-cycle current at 4000 volts from the incoming Washington Water Power lines. The machine is mounted on one end of a shaft in the middle of which is a 1000-kw. single-phase 2200-volt 25-cycle generator and at the other end of which is a d.c. machine rated at 1100 amperes and 550 volts. These three machines of Westinghouse manufacture operate at 550 rev. per min. When the load on the generator is light the d.c. machine runs as a generator and charges a 275-cell storage battery and when the load is heavy the d.c. machine runs as a motor taking current from the battery and assisting the three-phase induction motor in driving the single-phase generator. The single-phase generator has a somewhat larger power than the three-phase induction motor, the idea being that the three-phase motor in connection with the d.c machine will take nearly as full power from the line under a large variation of the single-phase load. At times when the single-phase load is excessive, the d.c. machine taking current from the battery makes up the deficiency. By this method a

* Extracted from the *Electric Railway Review*, October 26, 1907.

more uniform load from the three-phase line is had. The periods of light load are thus diminished and the peak of heavy load materially flattened. These machines are mounted on a common bed plate, each machine having its own pair of bearings and all being connected by fixed couplings.

The station equipment also includes two battery boosters of 960 amp. rating and three 50-kw. exciter sets for the single-phase generators. These exciters are driven by 75-hp. Westinghouse motors taking three-phase current at 125 volts pressure.

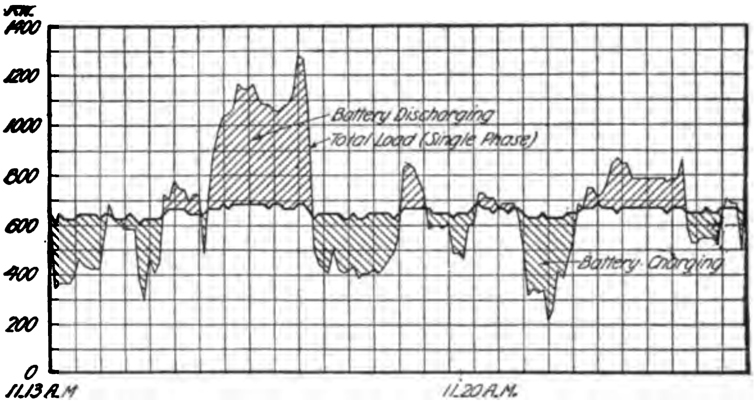


Fig. 291.—Power Curve Showing Smoothing Effect of Storage Battery in the Spokane and Inland Railway System.

The feed lines from the Washington Water Power plant enter the station on a gallery and pass to a hand-operated disconnecting oil switch and then through reactance coils, instrument transformers and down through the gallery floor to a busbar set. From this power bus, leads pass to the two Westinghouse type C oil switches, having remote control and located on the gallery floor. These switches admit of flexibility in feeding two sets of 4000-volt busbars at the back of the switchboard on the main floor. The motors of the phase-changing sets can be operated from either set of busbars. The oil switches for the motors are type F Westinghouse, from which energy is fed through starting resistance in the secondaries and rheostatic controllers to the induction motors.

The battery across which the d.c. machines are connected is made up of 275 chloride cells type R-33, having a discharge

rate of 2880 amperes furnished by the Electric Storage Battery Company. Fig. 291 gives an idea of the effect which the battery has on the supply line load. The single-phase railway load is very irregular while the three-phase supply line load is comparatively smooth. Regulation of the battery booster is controlled by a carbon regulator operated by changes of current in the three-phase supply line. Small changes in the current in this line cause the battery to charge from or discharge to the d.c. machine and thus keep the power supply load curve flat.

A 30-panel switchboard from which all the equipment and the battery are controlled is located in front of the gallery on the main floor. On the panels for the 750-hp. d.c. machines starting switches are provided for taking current from the battery for starting and thus not putting the large units on to the three-phase 4000-volt supply line until the machine is up to speed. The single-phase 25-cycle generators are controlled by Tirrill regulators. For synchronizing a synchroscope having an illuminated dial with an illuminated pointer is mounted on a pedestal in front of the switchboard.

The step-up transformers for raising the single-phase 25-cycle current from the generator pressure of 2200 volts to line pressure of 45,000 volts are mounted on cars made of structural iron shapes which stand in brick compartments. These compartments are provided with rails set in the concrete floor and in front of the row of compartments is a track running to a cross track by which the transformers can be taken to the end of the transformer room. The transformer car runs from the transfer car to the short track leading under the crane at the end of the station. From each one of the five 1250-kw., 2200 to 45,000-volt single-phase, step-up, oil-insulated, water-cooled transformers two leads pass to the gallery floor above to 60,000-volt type L Westinghouse oil switches and then through reactance coils and hand-operated disconnecting switches to the transmission line.

The local trolley section is fed from the phase-changing station through a 6600-volt panel on the station switchboard supplied by three 375-kw. 2200 to 6600-volt transformers.

When this system will be completed, there will be fifteen transformer substations located 10 miles apart. The equipment of each includes: Three 375-kw. oil-insulated trans-

formers connected in parallel and fed through one hand operated 60-000-volt oil switch provided with automatic release. Lightning arresters are placed on both high and low-tension sides of the transformers and 6600-volt oil switches serve to disconnect the transformers from the trolley.

APPENDIX

TABLE I.—CARRYING CAPACITY OF BARE AND INSULATED WIRE (Amperes).

Size, B. & S. Gage.	National Electric Code. A Rubber.	National Electric Code. B Weat'r-proof.	Insulated Wires in Moldings, Kennelly's Rule.	Bare Wire in Still Air, Temp. Rise 50° F.	Size, Cir. Mils.	National Electric Code. A Rubber.	National Electric Code. B Weat'r-proof.	Insulated Wires in Moldings, Kennelly's Rule.	Bare Wire in Still Air, Temp. Rise 50° F.
Solid									
18	3	5	4.5	6.0	300,000	270	400	281	373
17	..	..	5.4	7.2	400,000	330	500	349	463
16	6	8	6.4	8.5	500,000	390	590	413	549
15	..	..	7.6	10.2	600,000	450	680	474	631
14	12	16	9.1	12.1	700,000	500	760	532	708
13	..	..	10.8	14.4	800,000	550	840	587	781
12	17	23	12.9	17.1	900,000	600	920	641	852
11	..	..	15.3	20.4	1,000,000	650	1000	694	922
10	24	32	18.3	24.3	1,100,000	690	1080	746	991
9	..	..	21.6	28.7	1,200,000	730	1150	797	1058
Strand					1,300,000	770	1220	846	1123
8	33	46	31.3	41.5	1,400,000	810	1290	894	1187
7	..	..	37.3	49.5	1,500,000	850	1360	942	1250
6	46	65	44.3	58.8	1,600,000	890	1430	989	1312
5	54	77	52.5	69.7	1,700,000	930	1490	1035	1373
4	65	92	62.7	83.3	1,800,000	970	1550	1080	1433
3	76	110	74.4	98.8	1,900,000	1010	1610	1125	1492
2	90	113	88.6	117.6	2,000,000	1050	1670	1169	1550
1	107	156	105.4	140.0					
0	127	185	127.8	169.8					
00	150	220	151.7	201.5					
000	177	262	180.8	240.2					
0000	210	312	215.2	286.0					

The values in the 4th columns are such that twice the current given will cause a rise in temperature of 36° F.

TABLE II.—RECOMMENDED CURRENT CARRYING CAPACITIES FOR CABLES AND WATTS LOST PER FOOT

For each of four equally loaded paper-insulated lead-covered cables installed in adjacent ducts in the usual type of conduit system where the initial temperature does not exceed 70° F., the maximum safe temperature for continuous operation being taken at 150° F.

Size, B. & S. Gage.	Safe Current in Amp.	Watts* Lost per Foot at 150° F.	Size, Cir. Mils.	Safe Current in Amp.	Watts* Lost per Foot. at 150° F.
14	18	0.97	300,000	323	4.22
13	21	1.03	400,000	390	4.61
12	24	1.09	500,000	450	4.91
11	29	1.15	600,000	505	5.16
10	33	1.25	700,000	558	5.36
9	38	1.39	800,000	607	5.56
8	45	1.53	900,000	650	5.71
7	53	1.67	1,000,000	695	5.86
6	64	1.85	1,100,000	740	6.01
5	76	2.08	1,200,000	780	6.13
4	91	2.31	1,300,000	820	6.25
3	108	2.54	1,400,000	857	6.37
2	125	2.77	1,500,000	895	6.49
1	146	3.00	1,600,000	933	6.61
0	168	3.23	1,700,000	970	6.73
00	195	3.46	1,800,000	1010	6.85
000	225	3.69	1,900,000	1045	6.97
0000	260	3.92	2,000,000	1085	7.09

TABLE III.—RECOMMENDED POWER CARRYING CAPACITY IN KILOWATTS DELIVERED.

THREE-CONDUCTOR, THREE-PHASE CABLES.

(Copyright, 1906, by Standard Underground Cable Co.)

Size, B. & S. Gage and Cir. Mils.	1,100 V.	2,200 V.	3,300 V.	4,000 V.	6,600 V.	11,000 V.	13,200 V.	22,000V
	Kilowatts.							
6	92	183	275	333	549	915	1098	1831
5	104	217	326	395	652	1087	1304	2174
4	130	260	390	473	781	1301	1562	2603
3	154	309	463	562	927	1544	1854	3089
2	179	358	536	650	1073	1788	2145	3575
1	209	418	626	759	1253	2088	2506	4176
0	240	481	721	874	1442	2402	2884	4805
00	279	558	836	1014	1674	2788	3347	5577
000	322	644	965	1172	1931	3217	3862	6435
0000	372	744	1115	1352	2231	3717	4462	7435
250,000	413	827	1240	1503	2480	4132	4960	8264

SINGLE-CONDUCTOR CABLES, A. C. OR D. C.

Size, B. & S. Gage and Cir. Mils.	125 V.	250 V.	500 V.	1,100 V.	2,200 V.	3,300 V.	6,600 V.	11,000V
	Kilowatts.							
6	8.0	16.0	32	70	141	211	422	704
5	9.5	19.0	38	84	167	251	502	836
4	11.4	22.8	45	100	200	300	601	1001
3	13.5	27.0	54	119	238	356	713	1188
2	15.6	31.2	62	138	275	413	825	1375
1	18.3	36.5	73	161	321	482	964	1606
0	21.0	42.0	84	185	370	554	1104	1848
00	24.4	48.8	97	215	429	644	1287	2145
000	28.1	56.3	113	248	495	743	1485	2475
0000	32.5	65.0	130	286	572	858	1716	2860
300,000	40.5	80.8	162	355	711	1066	2132	3553
400,000	48.8	97.5	195	429	858	1287	2574	4290
500,000	56.3	112.5	225	495	990	1485	2970	4950
600,000	63.1	126.3	253	556	1111	1667	3333	5555
700,000	69.8	139.5	279	614	1228	1841	3683	6138
800,000	75.9	151.8	304	668	1335	2003	4006	6677
900,000	81.3	162.5	325	715	1430	2145	4290	7150
1,000,000	86.9	173.8	348	764	1529	2294	4587	7645
1,100,000	92.5	185.0	370	814	1628	2442	4884	8140
1,200,000	97.5	195.0	390	858	1716	2574	5148	8580
1,400,000	107.1	214.3	429	943	1885	2828	5656	9427
1,500,000	111.9	223.8	448	985	1969	2954	5907	9845
1,600,000	116.6	233.3	467	1026	2053	3079	6158	10263
1,700,000	121.3	242..5	485	1067	2134	3201	6402	10670
1,800,000	126.3	252.5	505	1111	2222	3333	6666	11110
2,000,000	135.3	271.3	543	1194	2387	3581	7161	11935

These tables are based on the "Recommended Current Carrying Capacity of Cables." A power-factor = 1 was used in the calculation and hence the values found in the last table are correct for direct currents For alternating currents the kilowatts given in both tables must be multiplied by the power-factor of the delivered load.

TABLE IV.—EQUIVALENT CONDUCTOR AREAS

Of Single Conductors of any Size, from 0000 to No. 15 in a Stated Number of Smaller Conductors.

Size, B.&S. Gage.	In 2 Conductors.	In 4 Conductors.	In 8 Conductors.	In 16 Conductors.	In 32 Conductors.	In 64 Conductors.	In 2 Conductors, One Each of:
0000	No. 0	No. 3	No. 6	No. 9	No. 12	No. 15	Nos. 00 and 1
000	" 1	" 4	" 7	" 10	" 13	" 16	" 0 " 2
00	" 2	" 5	" 8	" 11	" 14	" 17	" 1 " 3
0	" 3	" 6	" 9	" 12	" 15	" 18	" 2 " 4
1	" 4	" 7	" 10	" 13	" 16	....	" 3 " 5
2	" 5	" 8	" 11	" 14	" 17	....	" 4 " 6
3	" 6	" 9	" 12	" 15	" 18	....	" 5 " 7
4	" 7	" 10	" 13	" 16	....	....	" 6 " 8
5	" 8	" 11	" 14	" 17	....	....	" 7 " 9
6	" 9	" 12	" 15	" 18	....	....	" 8 "10
7	" 10	" 13	" 16	....	....	....	" 9 "11
8	" 11	" 14	" 17	....	....	....	" 10 "12
9	" 12	" 15	" 18	....	....	....	" 11 "13
10	" 13	" 16	....	....	....	....	" 12 "14
11	" 14	" 17	....	....	....	....	" 13 "15
12	" 15	" 18	....	....	....	....	" 14 "16
13	" 16	....	....	....	....	....	" 15 "17
14	" 17	....	....	....	....	....	" 16 "18
15	" 18	....	....	....	....	....	....

For the same temperature rise more current can be carried by using divided circuits, and the greater the number of divided circuits for the same equivalent cross-section, the greater the amount of current that can be carried. (See Table of Carrying Capacities.)

TABLE V.—WATTS PER FOOT LOST IN SINGLE-CONDUCTOR CABLES AT DIFFERENT MAXIMUM TEMPERATURE WITH DIFFERENT CURRENTS.

Size, B. & S. Gage.	Current in Amperes.					
6	66	81	93	104	114	123
5	74	91	105	117	128	138
4	84	102	117	131	144	153
3	93	114	132	148	161	175
2	105	128	148	166	181	196
1	118	148	166	186	203	220
0	132	162	187	209	228	247
00	149	181	210	235	256	277
000	166	204	235	263	288	311
0000	186	229	264	295	323	350
Cir. Mils.						
300,000	222	273	315	352	385	416
400,000	248	315	363	406	445	480
500,000	288	352	406	455	498	537
600,000	315	385	445	497	545	587
700,000	341	416	480	538	588	635
800,000	364	446	514	575	628	679
900,000	386	473	545	610	666	720
1,000,000	407	498	575	642	703	758
1,100,000	426	522	602	674	736	796
1,200,000	446	546	630	705	772	833
1,300,000	462	568	655	732	802	866
1,400,000	480	590	681	761	834	900
1,500,000	496	610	704	788	862	931
1,600,000	512	629	726	812	889	960
1,700,000	529	649	750	837	916	990
1,800,000	543	667	770	862	943	1018
1,900,000	557	686	792	886	970	1048
2,000,000	573	705	813	910	995	1075
Temp. of Cond. in Degrees F.	**Watts Lost per Foot.**					
100	1.81	2.71	3.62	4.52	5.43	6.33
125	1.91	2.87	3.82	4.78	5.73	6.69
150	2.00	3.00	4.00	5.00	6.00	7.00

The watts lost per foot means the amount of electric power lost in heating the conductor, and is equal to the product of the resistance per foot of cable times the square of the current in amperes.

For two-conductor cables the watts corresponding to the different currents must be multiplied by two, and to obtain the currents corresponding to the watts in the table, multiply the currents given in the table by 0.707.

For three-conductor cables the watts corresponding to the currents in the table must be multiplied by 3, and to obtain the currents corresponding to the watts in the table, multiply the currents given in the table by 0.577.

TABLE VI.—RUBBER-COVERED WIRE

INSULATION FOR VOLTAGES BETWEEN 0 AND 600, AS RECOMMENDED BY NATIONAL BOARD OF FIRE UNDERWRITERS.

B. & S. Gage	Thickness
18 to 16	$\frac{1}{32}$ inch
15 to 8	$\frac{3}{64}$ "
7 to 2	$\frac{1}{16}$ "
1 to 0000	$\frac{5}{64}$ "
Circ. mils.	
250,000 to 500,000	$\frac{3}{32}$ "
500,000 to 1,000,000	$\frac{7}{64}$ "
Over 1,000,000	$\frac{1}{8}$ "

TABLE VII.—INSULATION FOR VOLTAGES BETWEEN 600 AND 3500.

B. & S. Gage	Thickness
14 to 1	$\frac{3}{32}$ inch
0 to 0000	$\frac{3}{32}$ " covered by tap or braid
Circ. mils.	
250,000 to 500,000	$\frac{3}{32}$ " " " "
Over 500,000	$\frac{1}{8}$ " " " "

TABLE VIII.—VARNISHED CAMBRIC INSULATED CABLES.—(GENERAL ELECTRIC Co.)

SINGLE CONDUCTOR.

Size, B. & S. Gage.	1,000 V. Working.			3,000 V. Working.			5,000 V. Working.			7,000 V. Working.			10,000 V. Working.			15,000 V. Working.		
	Thick. Insul., Ins.	Thick. Lead, Ins.	Dia. in Ins.	Thick. Insul., Ins.	Thick. Lead, Ins.	Dia. in Ins.	Thick. Insul., Ins.	Thick. Lead, Ins.	Dia. in Ins.	Thick. Insul., Ins.	Thick. Lead, Ins.	Dia. in Ins.	Thick. Insul., Ins.	Thick. Lead, Ins.	Dia. in Ins.	Thick. Insul., Ins.	Thick. Lead, Ins.	Dia. in Ins.
Solid 6	1/16	3/64	0.40	3/32	3/64	0.46	9/64	3/64	0.55	3/16	1/16	0.68	1/4	1/16	0.80	11/32	3/32	1.05
4	1/16	3/64	0.44	3/32	3/64	0.50	9/64	1/16	0.63	3/16	1/16	0.72	1/4	1/16	0.84	11/32	3/32	1.10
Strand 6	1/16	3/64	0.42	3/32	3/64	0.48	9/64	3/64	0.57	3/16	1/16	0.70	1/4	1/16	0.82	11/32	3/32	1.08
4	1/16	3/64	0.47	3/32	3/64	0.53	9/64	1/16	0.65	3/16	1/16	0.75	1/4	1/16	0.87	11/32	3/32	1.12
2	1/16	1/16	0.56	3/32	1/16	0.62	9/64	1/16	0.71	3/16	1/16	0.81	1/4	5/64	0.96	11/32	3/32	1.18
1	5/64	1/16	0.63	3/32	1/16	0.66	5/32	1/16	0.79	3/16	5/64	0.88	1/4	3/32	1.04	3/8	3/32	1.29
0	5/64	1/16	0.67	3/32	1/16	0.70	5/32	5/64	0.86	3/16	3/32	0.95	1/4	3/32	1.08	3/8	3/32	1.33
00	5/64	1/16	0.72	3/32	1/16	0.75	5/32	3/32	0.94	3/16	3/32	1.00	1/4	3/32	1.12	3/8	3/32	1.37
000	5/64	1/16	0.77	3/32	5/64	0.83	5/32	3/32	0.99	3/16	3/32	1.05	1/4	3/32	1.17	3/8	3/32	1.42
0000	3/32	5/64	0.89	7/64	5/64	0.92	5/32	3/32	1.04	3/16	3/32	1.11	1/4	3/32	1.23	3/8	3/32	1.48
Cir. Mils.																		
250,000	3/32	3/32	0.97	7/64	3/32	1.00	5/32	3/32	1.09	3/16	3/32	1.15	1/4	3/32	1.28	3/8	3/32	1.53
300,000	3/32	3/32	1.03	1/8	3/32	1.09	5/32	3/32	1.15	13/64	3/32	1.24	1/4	3/32	1.38	3/8	7/64	1.63
400,000	3/32	3/32	1.12	1/8	3/32	1.16	5/32	3/32	1.24	13/64	3/32	1.36	1/4	3/32	1.48	3/8	1/8	1.73
500,000	3/32	3/32	1.21	1/8	3/32	1.27	5/32	3/32	1.33	7/32	3/32	1.46	1/4	7/64	1.57	3/8	1/8	1.82
750,000	7/64	3/32	1.42	1/8	3/32	1.45	11/64	7/64	1.58	7/32	7/64	1.67	17/64	7/64	1.80	25/64	1/8	2.05
1,000,000	7/64	3/32	1.58	1/8	3/32	1.61	11/64	7/64	1.73	7/32	1/8	1.85	17/64	1/8	1.96	13/32	1/8	2.23
1,250,000	1/8	7/64	1.78	1/8	7/64	1.77	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
1,500,000	1/8	1/8	1.93	1/8	1/8	1.93	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
2,000,000	1/8	1/8	2.15	1/8	1/8	2.15	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....

The columns with "Dia. in Ins." is over all diameter of the finished cable and is approximately the same for either braided or leaded.

TABLE IX.—VARNISHED CAMBRIC INSULATED CABLES.—(GENERAL ELECTRIC CO.)

TRIPLE CONDUCTORS.

(All dimensions given in inches.)

Size, B. & S. Gage.	1,000 V. Working.			3,000 V. Working.			5,000 V. Working.			7,000 V. Working.			10,000 V. Working.			15,000 V. Working.		
	Thick. Insul.	Thick. Lead.	Dia.	Thick. Insul.	Thick. Lead.	Dia.	Thick. Insul.	Thick. Lead.	Dia.	Thick. Insul.	Thick. Lead.	Dia.	Thick. Insul.	Thick. Lead.	Dia.	Thick. Insul.	Thick. Lead.	Dia.
6	$\frac{1}{16}$–$\frac{3}{32}$	$\frac{1}{16}$	0.87	$\frac{5}{64}$–$\frac{5}{64}$	$\frac{5}{64}$	1.03	$\frac{3}{32}$–$\frac{5}{64}$	$\frac{3}{32}$	1.20	$\frac{1}{8}$–$\frac{1}{8}$	$\frac{3}{32}$	1.42	$\frac{3}{32}$–$\frac{3}{32}$	$\frac{3}{32}$	1.62	$\frac{3}{16}$–$\frac{3}{16}$	$\frac{3}{32}$	1.82
4	$\frac{1}{16}$–$\frac{3}{32}$	$\frac{1}{16}$	0.97	$\frac{5}{64}$–$\frac{5}{64}$	$\frac{5}{64}$	1.14	$\frac{3}{32}$–$\frac{5}{64}$	$\frac{3}{32}$	1.30	$\frac{1}{8}$–$\frac{1}{8}$	$\frac{3}{32}$	1.53	$\frac{3}{32}$–$\frac{3}{32}$	$\frac{3}{32}$	1.73	$\frac{3}{16}$–$\frac{3}{16}$	$\frac{3}{32}$	1.92
2	$\frac{1}{16}$–$\frac{3}{32}$	$\frac{5}{64}$	1.17	$\frac{5}{64}$–$\frac{5}{64}$	$\frac{5}{64}$	1.27	$\frac{3}{32}$–$\frac{5}{64}$	$\frac{3}{32}$	1.43	$\frac{1}{8}$–$\frac{1}{8}$	$\frac{3}{32}$	1.66	$\frac{3}{32}$–$\frac{3}{32}$	$\frac{3}{32}$	1.86	$\frac{3}{16}$–$\frac{3}{16}$	$\frac{1}{8}$	2.11
1	$\frac{1}{16}$–$\frac{3}{32}$	$\frac{5}{64}$	1.25	$\frac{5}{64}$–$\frac{5}{64}$	$\frac{3}{32}$	1.38	$\frac{3}{32}$–$\frac{3}{32}$	$\frac{3}{32}$	1.55	$\frac{1}{8}$–$\frac{1}{8}$	$\frac{1}{8}$	1.81	$\frac{11}{64}$–$\frac{11}{64}$	$\frac{1}{8}$	2.10	$\frac{11}{64}$–$\frac{11}{64}$	$\frac{1}{8}$	2.30
0	$\frac{1}{16}$–$\frac{3}{32}$	$\frac{5}{64}$	1.34	$\frac{5}{64}$–$\frac{1}{16}$	$\frac{3}{32}$	1.50	$\frac{3}{32}$–$\frac{3}{32}$	$\frac{3}{32}$	1.64	$\frac{1}{8}$–$\frac{1}{8}$	$\frac{1}{8}$	1.89	$\frac{11}{64}$–$\frac{11}{64}$	$\frac{1}{8}$	2.19	$\frac{11}{64}$–$\frac{11}{64}$	$\frac{1}{8}$	2.39
00	$\frac{1}{16}$–$\frac{3}{32}$	$\frac{3}{32}$	1.47	$\frac{5}{64}$–$\frac{1}{16}$	$\frac{3}{32}$	1.60	$\frac{3}{32}$–$\frac{3}{32}$	$\frac{3}{32}$	1.74	$\frac{1}{8}$–$\frac{1}{8}$	$\frac{1}{8}$	1.99	$\frac{11}{64}$–$\frac{11}{64}$	$\frac{1}{8}$	2.29	$\frac{11}{64}$–$\frac{11}{64}$	$\frac{1}{8}$	2.48
000	$\frac{1}{16}$–$\frac{3}{32}$	$\frac{3}{32}$	1.58	$\frac{3}{32}$–$\frac{1}{16}$	$\frac{3}{32}$	1.78	$\frac{3}{32}$–$\frac{3}{32}$	$\frac{1}{8}$	1.91	$\frac{1}{8}$–$\frac{1}{8}$	$\frac{1}{8}$	2.10	$\frac{11}{64}$–$\frac{11}{64}$	$\frac{1}{8}$	2.40	$\frac{11}{64}$–$\frac{11}{64}$	$\frac{1}{8}$	2.59
0000	$\frac{5}{64}$–$\frac{3}{32}$	$\frac{1}{8}$	1.84	$\frac{3}{32}$–$\frac{1}{16}$	$\frac{1}{8}$	1.97	$\frac{3}{32}$–$\frac{3}{32}$	$\frac{1}{8}$	2.03	$\frac{1}{8}$–$\frac{1}{8}$	$\frac{1}{8}$	2.23	$\frac{11}{64}$–$\frac{11}{64}$	$\frac{1}{8}$	2.52	$\frac{11}{64}$–$\frac{11}{64}$	$\frac{1}{8}$	2.72
250,000	$\frac{3}{32}$–$\frac{5}{64}$	$\frac{1}{8}$	1.97	$\frac{3}{32}$–$\frac{1}{16}$	$\frac{1}{8}$	2.07	$\frac{3}{32}$–$\frac{3}{32}$	$\frac{1}{8}$	2.13	$\frac{1}{8}$–$\frac{1}{8}$	$\frac{1}{8}$	2.33	$\frac{11}{64}$–$\frac{11}{64}$	$\frac{1}{8}$	2.63	$\frac{11}{64}$–$\frac{11}{64}$	$\frac{1}{8}$	2.82

Under "Thickness of Insulation," the first column is the thickness of insulation on each conductor and the second column is the thickness over all.

The column "Diameter" is the over-all diameter of the finished cable and is approximately the same for either braided or leaded.

TABLE X.—SPARKING DISTANCES.

The following table gives the sparking distances between sharp points corresponding to different alternating current voltages when the ratio between maximum and mean effective voltages is $\sqrt{2}=1.41$ The values given were derived from experiments made by the Standard Underground Cable Co.

Volts.	Spark Distance, A or B.	Volts.	Spark Distance. A.	Spark Distance. B.	Volts.	Spark Distance. A.	Spark Distance. B.
1,000	0.028	21,000	1.092	1.097	44,000	2.370	2.506
2,000	0.098	22,000	1.143	1.150	45,000	2.432	2.580
3,000	0.159	23,000	1.195	1.206	46,000	2.495	2.60
4,000	0.216	24,000	1.247	1.260	47,000	2.560	
5,000	0.270	25,000	1.300	1.314	48,000	2.625	
6,000	0.324	26,000	1.353	1.373	49,000	2.692	
7,000	0.378	27,000	1.405	1.427	50,000	2.760	
8,000	0.432	28,000	1.460	1.485			
9,000	0.487	29,000	1.512	1.540			
10,000	0.540	30,000	1.566	1.600			
11,000	0.595	31,000	1.620	1.655			
12,000	0.644	32,000	1.675	1.712			
13,000	0.695	33,000	1.728	1.772			
14,000	0.746	34,000	1.785	1.833			
15,000	0.797	35,000	1.840	1.895			
16,000	0.845	36,000	1.900	1.958			
17,000	0.897	37,000	1.945	2.020			
18,000	0.945	38,000	2.012	2.085			
19,000	0.995	39,000	2.062	2.153			
20,000	1.042	40,000	2.127	2.220			
		41,000	2.190	2.290			
		42,000	2.247	2.360			
		43,000	2.308	2.434			

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS' TABLE.

Volts.	Spark Distance.
10,000	.47
20,000	1.04
25,000	1.30
30,000	1.625
40,000	2.45
45,000	2.95
50,000	3.55

Column "A" gives spark distance with 10-in. concave metallic shields, the plane of whose edges was 1 in. back of the needle points.

Column "B" gives the spark distance without shields.

INDEX

INDEX